Monte Carlo for Early LHC Physics

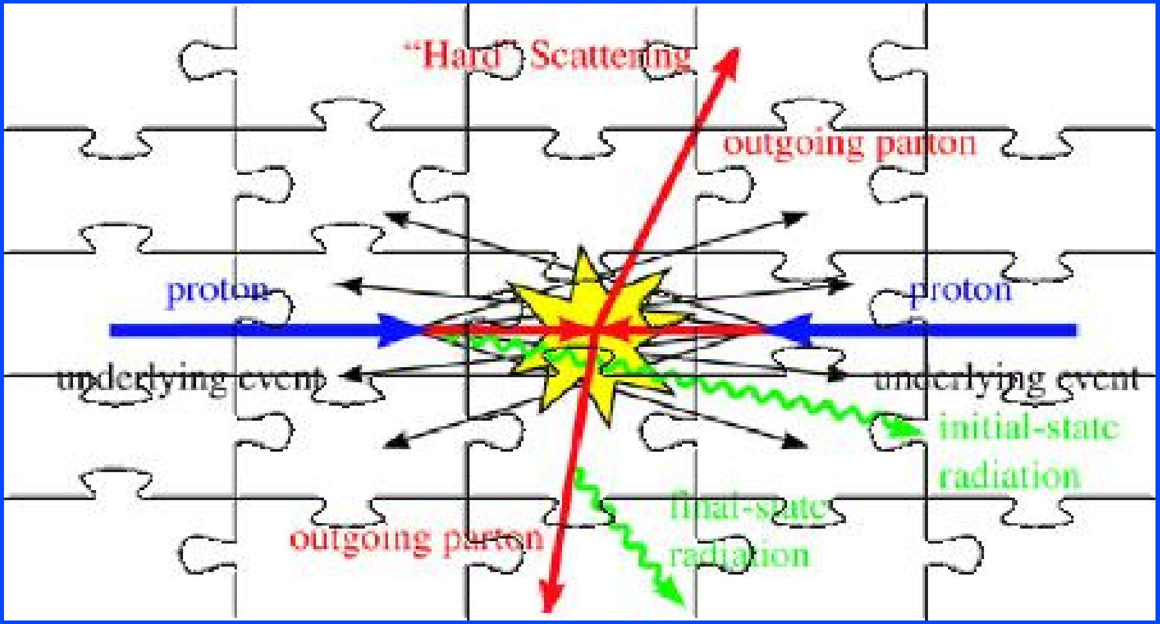
Stephen Mrenna
Scientist I
Computing Division
Fermilab

Understanding Cross Sections @ LHC: many pieces to the puzzle

LO, NLO and NNLLO, NLO and NNLO calculations
K-factors

Benchmark cross sections and pdf correlations

PDFs with uncertainties



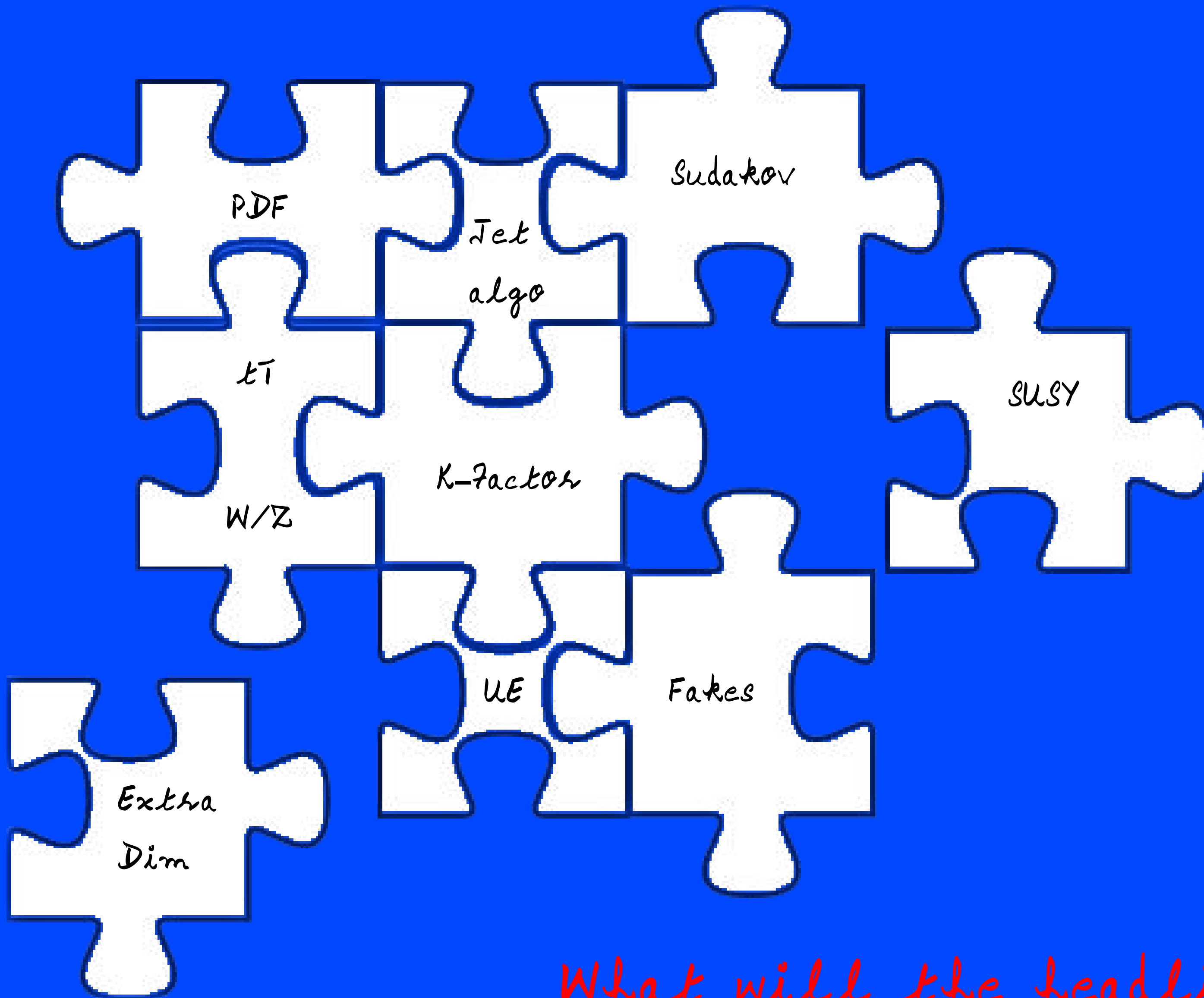
Underlying event and minimum bias

Fragmentation/Hadronization

Sudakov form factors

Jet algorithms and jet reconstruction

(How) will the puzzle pieces fit together?



What will the headlines be?

The New York Times

1315 Physicists Report Failure In Search for Supersymmetry

The negative result illustrates

Experimental Evidence For More Dimensions Reported

Gordon L. Kane
May 2011

The worldview of physicists working on unification theories has been changing rapidly recently. That change culminated in March, at the 46th annual Recontres de Moriond conference in Les Arcs, France, with the announcement of some startling data from CERN's Large Hadron Collider (LHC).

More than two hundred years ago, Charles Augustin Coulomb showed that the electrical force had the same form as the gravitational

ory. Because the work was well ahead of its time, and because of World War II, Klein's insight went largely unnoticed. See L. O'Raifeartaigh, *The Dawning of Gauge Theory*, Princeton University Press, 1977.)

The fields of the higher-dimensional theory were the gravitational tensor field, the electromagnetic vector potential field and a scalar field. Of course, the theories of electricity and magnetism were unified without extra dimensions by Maxwell, and the

Missing Energy Events are Confirmed

1) Events are real

2) Not conventional physics
   $W \to \tau$, $Q\bar{Q}$, $Z^0 g$
   $\hookrightarrow \nu\nu$

3) Not $X \to Z^0 + \text{jet(s)}$
   $\hookrightarrow \nu\nu$

4) Not $Z^0 \to X_1 X_2$
   $\hookrightarrow \nu$'s or stable
   $\hookrightarrow$ jet(s)

(ORIGINAL TRANSPARENCY FROM 1986 UA1 'DISCOVERY' OF SUSY

ASPEN CONF, 1986

Table 1. Predicted rates for processes giving large missing transverse energy events passing all event selection cuts.

Data

Process	Events (total)	Events with $L_T < 0$	Events with $L_T < 0$ and $E_T^{jet} < 40$ GeV
$W \to e\nu$ $W \to \mu\nu$ $W \to \tau\nu \to$ leptons	3.6	2.0	1.4
$W \to \tau\nu$ $\to \nu\bar{\nu}$ + hadrons	34.7	8.0	7.1
$W \to c\bar{s}$	<0.1	<0.1	<0.1
$Z^0 \to \tau^+\tau^-$	0.5	0.1	0.1
$Z^0 \to \nu\bar{\nu}$ (3 neutrino species)	7.4	7.1	5.6
$Z^0 \to c\bar{c}$ and $b\bar{b}$	<0.1	<0.1	<0.1
$c\bar{c}$ and $b\bar{b}$ (direct production)	0.2	0.2	0.2
Jet fluctuations (fake missing energy)	3.8	3.4	3.4
TOTAL	56 52.2	24 20.8 ± 5.1 ± 1.0	17.8 ± 3.7 ± 1.0

How well do we understand the Standard Model (@ high pT)?

It seems to work very well ... how well?

What does that mean for the LHC?

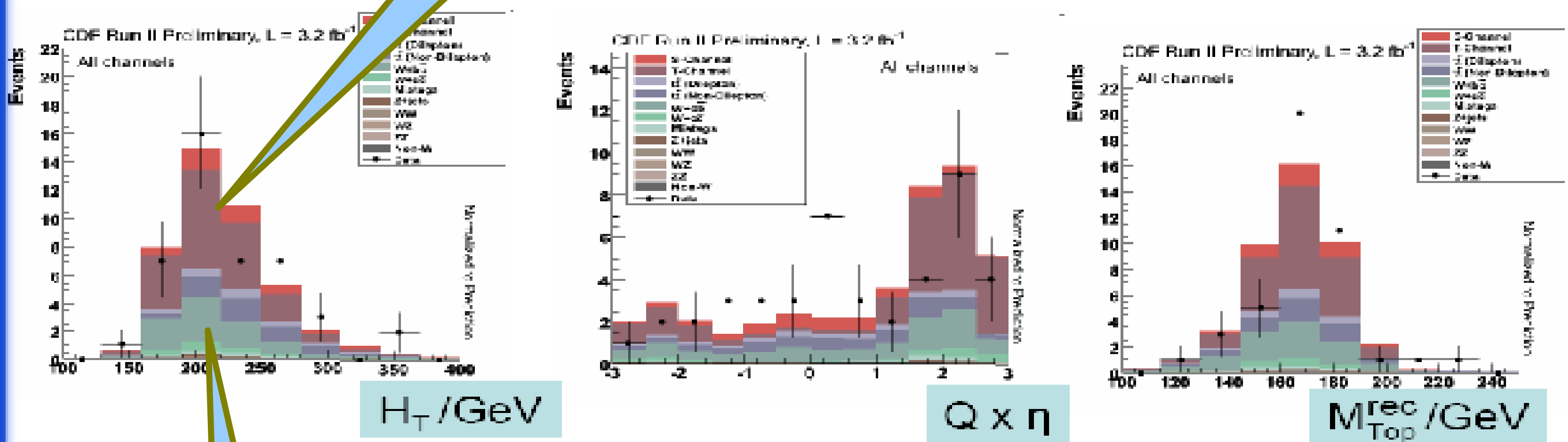
What theory/analysis work is needed?

3 Measures of How Well We Understand the SM @ High-Pt (all based on TeV results)

- “Discovery”
- Global Analysis
- Null search for New Physics

#1: Single Top “Discovery”

SD>0.72



Single Top

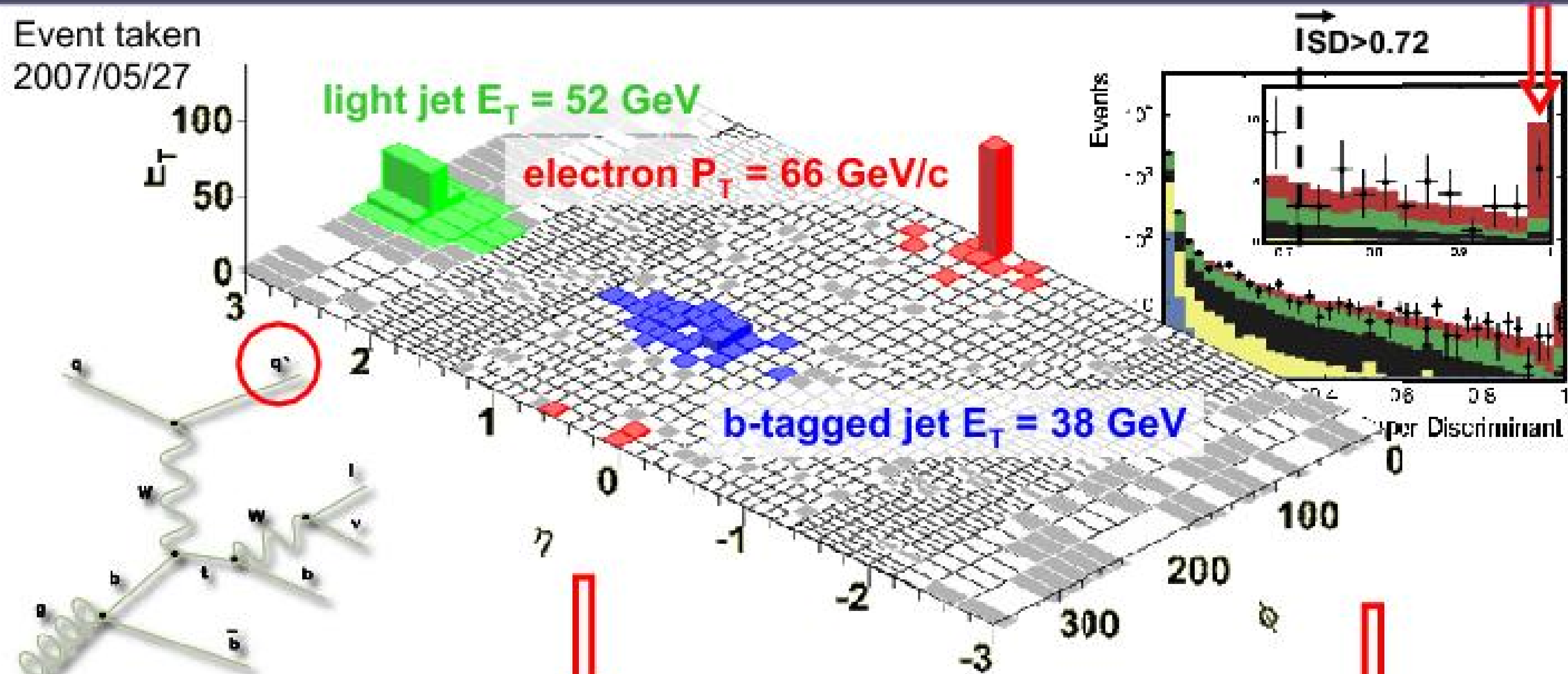
tt~
Wbb~

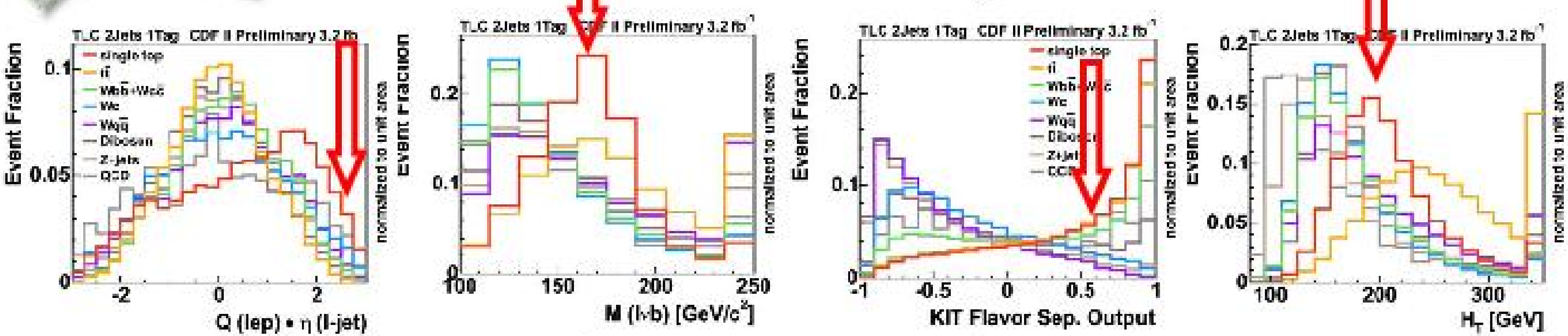
Purity S/B ~ 1.2

Difficult Topology

A Golden Event

Event taken
2007/05/27





#2: Global Analysis @ High Pt

- Define high-p_T objects reconstructed in experiment (CDF in this case)

- Generate-Simulate Monte Carlo events and reconstruct same objects

- Introduce a correction model (fakes, K-factors, uncertainties) and refine

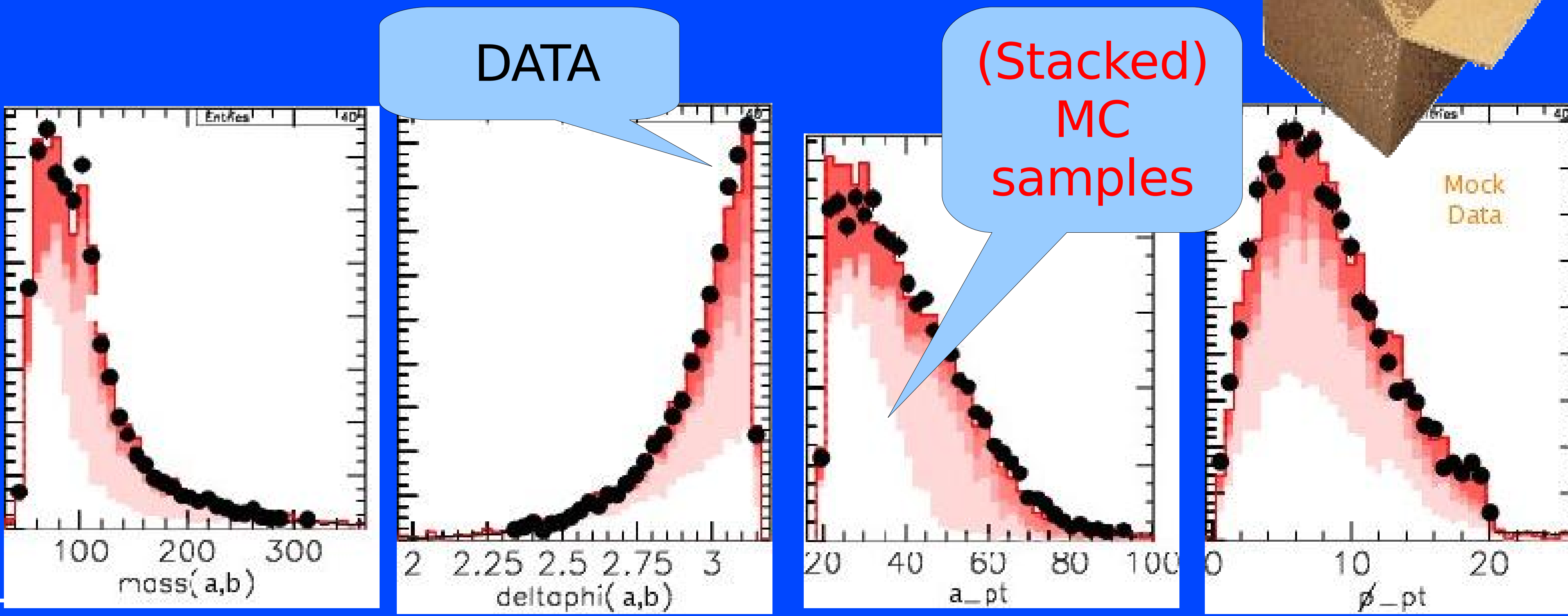
- Compare counts and shapes in different final states

Final State: 1a 1b 1pmiss

1 high-P_T object "a"+ any number low-P_T

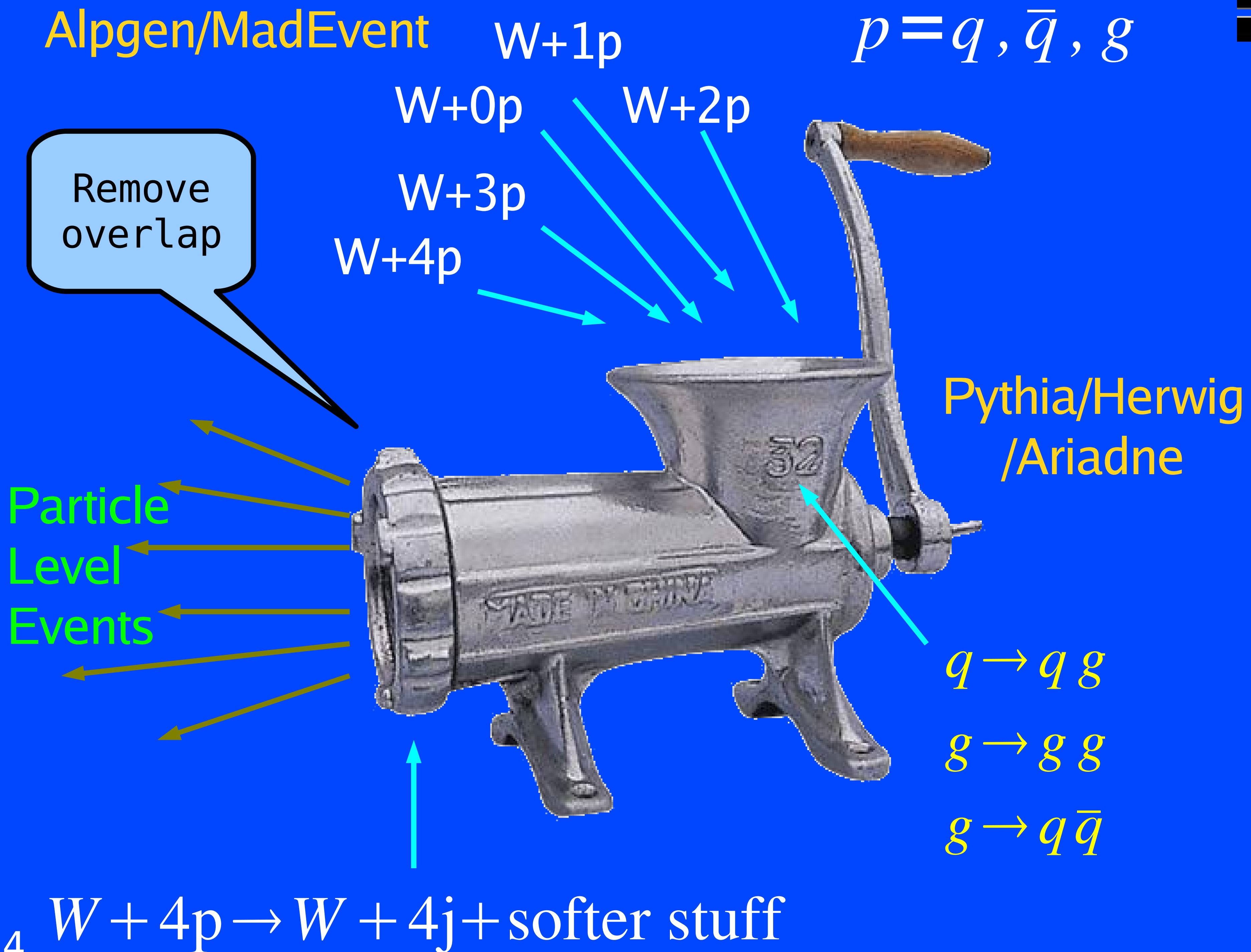
1 high-P_T object "b"+ any number low-P_T

Significant missing -P_T



Modeling the SM in practice

- We know the importance of PDFs, NLO …
- In practice, we try to use the data to calculate all orders, pert and non
- Data(Y) = MC(Y)/MC(X) * Data(X)
  - Other theoretical developments are used mainly for cross checks or to model signals
- Like mixing cocktails or making sausage


Alpgen/MadEvent
W+1p
W+0p
W+2p
W+3p
W+4p
$p = q, \bar{q}, g$
Remove overlap
Pythia/Herwig /Ariadne
Particle Level Events
$q \to q\, g$
$g \to g\, g$
$g \to q\, \bar{q}$
$W + 4\mathrm{p} \to W + 4\mathrm{j} + \text{softer stuff}$

CDF Run II Preliminary (2.0 fb^{-1})

The calculation of σ accounts for the trials factor

Final State	Data	Background	σ
$be^{+}\not p$	680	817.7 ± 9.2	−2.7
$\gamma\tau^{+}$	1371	1217.6 ± 13.3	+2.2
$\mu^{\pm}\tau^{\pm}$	63	35.2 ± 2.8	+1.7
b2j$\not p$ high-Σp_T	255	327.2 ± 8.9	−1.7
2j$\tau^{\pm}$ low-Σp_T	574	670.3 ± 8.6	−1.5
3j$\tau^{\pm}$ low-Σp_T	148	199.9 ± 5.2	−1.4
$e^{\pm}\not p\tau^{\pm}$	36	17.2 ± 1.7	+1.4
2j$\tau^{\pm}\tau^{\mp}$	33	62.1 ± 4.3	−1.3
$e^{\pm}$j	741710	764832 ± 6447.2	−1.3
j2$\tau^{\pm}$	105	150.8 ± 6.3	−1.2
$e^{\pm}$2j	256946	249148 ± 2201.5	+1.2
2bj low-Σp_T	279	352.5 ± 11.9	−1.1
j$\tau^{\pm}$ low-Σp_T	1365	1525.3 ± 15	−1.1
2b2j low-Σp_T	108	153.5 ± 6.8	−1
b$\mu^{\pm}\not p$	528	613.5 ± 8.7	−0.9
$\mu^{\pm}\gamma\not p$	323	311 ± 12.1	0.8
2bγ	118	70.5 ± 7.9	+0.1
8j	14	13.1 ± 1.4	0
7j	113	97.8 ± 12.2	0
6j	683	650.7 ± 37.3	0
5j	3157	3178.7 ± 67.1	0
4j high-Σp_T	89546	89096.6 ± 935.2	0
4j low-Σp_T	14872	14809.6 ± 186.3	0
4j2γ	46	46.4 ± 3.9	0
4j$\tau^{\pm}$ high-Σp_T	29	26.6 ± 1.7	0
4j$\tau^{\pm}$ low-Σp_T	43	68.1 ± 3.3	0
4j$\not p$ high-Σp_T	1084	1012 ± 62.9	0
4j$\gamma\tau^{\pm}$	19	10.8 ± 2	0
4j$\gamma\not p$	62	104.2 ± 22.4	0
4jγ	7962	8271.2 ± 245.1	0
4j$\mu^{\pm}\not p$	574	590.5 ± 13.6	0
4j$\mu^{\pm}\tau^{\mp}$	38	48.4 ± 6.2	0
4j$\mu^{\pm}$	1363	1350.1 ± 37.7	0
3j high-Σp_T	159926	159143 ± 1061.8	0
3j low-Σp_T	62681	64213.1 ± 498	0
3j2γ	151	177.5 ± 7.1	0
3j$\tau^{\pm}$ high-Σp_T	68	76.9 ± 3	0
3j$\not p$ high-Σp_T	1706	1599.4 ± 77.6	0
3j$\not p$ low-Σp_T	42	36.2 ± 5.7	0
3j$\gamma\tau^{\pm}$	[illegible]	[illegible] ± 3.6	0
3j$\gamma\not p$	204	[illegible]	[illegible]
3jγ	24639	[illegible]	[illegible]
3j$\mu^{\pm}\not p$	2884	2971.[illegible]	[illegible]
3j$\mu^{\pm}\gamma\not p$	10	8.6 ± [illegible]	[illegible]
3j$\mu^{\pm}\gamma$	15	7.9 ± [illegible]	[illegible]
3j$\mu^{\pm}\tau^{\mp}$	175	177.8 ± [illegible]	[illegible]
3j$\mu^{\pm}$	5032	4989.5 ± [illegible]	[illegible]
3b2j	23	28.9 ± [illegible]	[illegible]
3bj	82	82.6 ± [illegible]	[illegible]
3b	97	85.6 ± [illegible]	[illegible]
2$\tau^{\pm}$	468	512.7 ± [illegible]	[illegible]
2$\gamma\not p$	128	107.2 ± 6.[illegible]	[illegible]
2γ	5548	5562.8 ± 40.[illegible]	[illegible]
2j high-Σp_T	190773	190842 ± 781.[illegible]	[illegible]
2j low-Σp_T	165984	162530 ± 1581	[illegible]
2j2$\tau^{\pm}$	22	40.6 ± 3.2	0
2j2$\gamma\not p$	11	8 ± 2.4	0
2j2γ	580	581 ± 13.7	0
2j$\tau^{\pm}$ high-Σp_T	96	114.6 ± 3.3	0

Final State	Data	Background	σ
2j$\not p$ high-Σp_T	87	80.9 ± 5.8	0
2j$\not p$ low-Σp_T	114	79.5 ± 100.8	0
2j$\not p\tau^{\pm}$	18	13.2 ± 2.2	0
2j$\gamma\tau^{\pm}$	142	144.6 ± 5.7	0
2j$\gamma\not p$	908	980.3 ± 53.7	0
2jγ	71504	78021.4 ± 596.9	0
2j$\mu^{\pm}\tau^{\mp}$	16	19.3 ± 2.2	0
2j$\mu^{\pm}\not p$	17927	18340.6 ± 201.9	0
2j$\mu^{\pm}\gamma\not p$	31	27.7 ± 7.7	0
2j$\mu^{\pm}\gamma$	57	58.2 ± 13	0
2j$\mu^{\pm}\mu^{\mp}\not p$	11	7.8 ± 2.7	0
2j$\mu^{\pm}\mu^{\mp}$	958	924.9 ± 31.2	0
2j$\mu^{\pm}$	22461	23111.4 ± 366.6	0
2$e^{\pm}$j	14	13.8 ± 2.3	0
2$e^{-}e^{-}$	20	17.5 ± 1.7	0
2e^{-}	32	40.2 ± 3.4	0
2b high-Σp_T	606	689 ± 3.4	0
2b low-Σp_T	323	313.2 ± 10.3	0
2b3j low-Σp_T	38	37.4 ± 3.5	0
2b2j high-Σp_T	718	803.3 ± 12.7	0
2b[illegible] high-Σp_T	15	21.3 ± 2.8	0
[illegible]	32	30.7 ± 5.2	0
[illegible]	[illegible]4	17.3 ± 1.9	0
2[illegible]	22	21.8 ± 2	0
2[illegible]	[illegible]	14.4 ± 2.1	0
2[illegible]	[illegible]	967.1 ± 18.2	0
2[illegible]	26	31.3 ± 3.1	0
2bj[illegible]	71	64.5 ± 7.1	0
2bj$\mu^{\pm}\not p$	12	10.7 ± 1.9	0
2b$e^{\pm}$2j$\not p$	30	27.3 ± 2.2	0
2b$e^{\pm}$2j	73	66.5 ± 3.0	0
2b$e^{\pm}\not p$	22	19.1 ± 2.2	0
2b$e^{\pm}$j$\not p$	19	19.4 ± 2.2	0
2b$e^{\pm}$j	63	63 ± 3.4	0
2b$e^{\pm}$	96	92.1 ± 4.1	0
$\tau^{\pm}\tau^{\mp}$	856	872.5 ± 19	0
$\gamma\not p$	3793	3770.7 ± 127.3	0
$\mu^{\pm}$[illegible]	[illegible]	440.9 ± 7.3	0
[illegible]	[illegible]	[illegible].7 ± 3.4	0
[illegible]	[illegible]	[illegible] ± 2	0
[illegible]	[illegible]	[illegible]4827.6	0
[illegible]	[illegible]	[illegible]5	0
[illegible]	[illegible]	[illegible] ± 2.6	0
[illegible]	[illegible]	[illegible]58323 ± 707.7	0
j$\mu^{\pm}\gamma\not p$	171	171.1 ± 31	0
j$\mu^{\pm}\gamma$	152	190 ± 39.3	0

Final State	Data	Background	σ
j$\mu^{\pm}e^{\mp}\not p$	32	32.2 ± 10.9	0
j$\mu^{\pm}e^{\mp}\gamma$	14	11.5 ± 2.6	0
j$\mu^{\pm}\mu^{\mp}$	4852	4271.2 ± 185.4	0
j$\mu^{\pm}$	77589	76987.5 ± 930.2	0
$e^{\pm}$4j$\not p$	908	880.5 ± 13.2	0
$e^{\pm}$4jγ	25	29.2 ± 3.6	0
$e^{\pm}$4j	[illegible]	[illegible]	[illegible]
$e^{\pm}$3j$\tau^{\mp}$	[illegible]	[illegible]	[illegible]
$e^{\pm}$3j$\not p$	[illegible]	[illegible]	[illegible]
$e^{\pm}$3jγ	[illegible]	[illegible]	[illegible]
$e^{\pm}$3j	[illegible]	[illegible]	[illegible]
$e^{\pm}$2γ	[illegible]	[illegible]	[illegible]
$e^{\pm}$2j$\tau^{\pm}$	[illegible]	[illegible]	[illegible]
$e^{\pm}$2j$\tau^{\mp}$	[illegible]	[illegible]	[illegible]
$e^{\pm}$2j$\not p$	[illegible]	[illegible]	[illegible]
$e^{\pm}$2j$\gamma\not p$	[illegible]	[illegible]	[illegible]
$e^{\pm}$2jγ	398	342.8 ± 15.7	0
$e^{\pm}$2j$\mu^{\mp}\not p$	22	14.5 ± 1.9	0
$e^{\pm}$2j$\mu^{\mp}$	23	15.8 ± 2	0
$e^{\pm}\tau^{\pm}$	137	387 ± 5.3	0
$e^{\pm}\tau^{\mp}$	1333	1266 ± 12.3	0
$e^{\pm}\not p\tau^{\mp}$	109	136.1 ± 2.7	0
$e^{\pm}\not p$	960826	956579 ± 3077.7	0
$e^{\pm}\gamma\not p$	497	496.5 ± 10.3	0
$e^{\pm}\gamma$	3578	3539.9 ± 24.1	0
$e^{\pm}\mu^{\pm}\not p$	31	29.9 ± 1.6	0
$e^{\pm}\mu^{\mp}\not p$	109	99.4 ± 2.4	0
$e^{\pm}\mu^{\pm}$	45	28.5 ± 1.8	0
$e^{\pm}\mu^{\mp}$	350	313 ± 5.4	0
$e^{\pm}$j2γ	13	16.1 ± 3.9	0
$e^{\pm}$j$\tau^{\mp}$	366	419 ± 16.9	0
$e^{\pm}$j$\tau^{\pm}$	160	132.9 ± 3.5	0
$e^{\pm}$j$\not p\tau^{\mp}$	48	44.5 ± 3.3	0
$e^{\pm}$j$\not p\tau^{\pm}$	11	8.3 ± 1.5	0
$e^{\pm}$j$\not p$	121431	121023 ± 747.6	0
$e^{\pm}$j$\gamma\not p$	159	192.6 ± 10.9	0
$e^{\pm}$jγ	1369	[illegible]36.9 ± 36.9	0
$e^{\pm}$j$\mu^{\pm}\not p$	42	33 ± 2.9	0
$e^{\pm}$j$\mu^{\mp}\not p$	16	[illegible] ± 1.9	0
$e^{\pm}$j$\mu^{\mp}$	62	[illegible] ± 3.2	0
$e^{\pm}$j$\mu^{\pm}$	13	[illegible]	[illegible]
$e^{\pm}e^{-}$4j	14[illegible]	[illegible]	[illegible]
$e^{\pm}e^{-}$3j	[illegible]	[illegible]	[illegible]
$e^{\pm}e^{-}$2j$\not p$	[illegible]	[illegible]	[illegible]
$e^{\pm}e^{-}$2jγ	[illegible]	[illegible]	[illegible]
$e^{\pm}e^{-}$2j	[illegible]	[illegible]	[illegible]
$e^{\pm}e^{\pm}\tau^{\pm}$	[illegible]	[illegible]	[illegible]
$e^{\pm}e^{-}\not p$	[illegible]	[illegible]	[illegible]
$e^{\pm}e^{-}\gamma$	[illegible]	[illegible]	[illegible]
$e^{\pm}e^{-}$j$\not p$	[illegible]	[illegible]	[illegible]
$e^{\pm}e^{-}$jγ	[illegible]	[illegible]	[illegible]
$e^{\pm}e^{-}$j	1[illegible]	[illegible]	[illegible]
$e^{\pm}e^{-}$	989[illegible]	[illegible]	[illegible]
b6j	51	[illegible]	[illegible]
b5j	237	192.5 ± [illegible]	0
b4j high-Σp_T	26	28.4 ± 2.6	0
b4j low-Σp_T	686	827.7 ± 15.9	0
b3j high-Σp_T	12081	12071 ± 84.1	0
b3j low-Σp_T	2974	2873 ± 31	0

399 final states:
a lot of information

$2\,fb^{-1}$

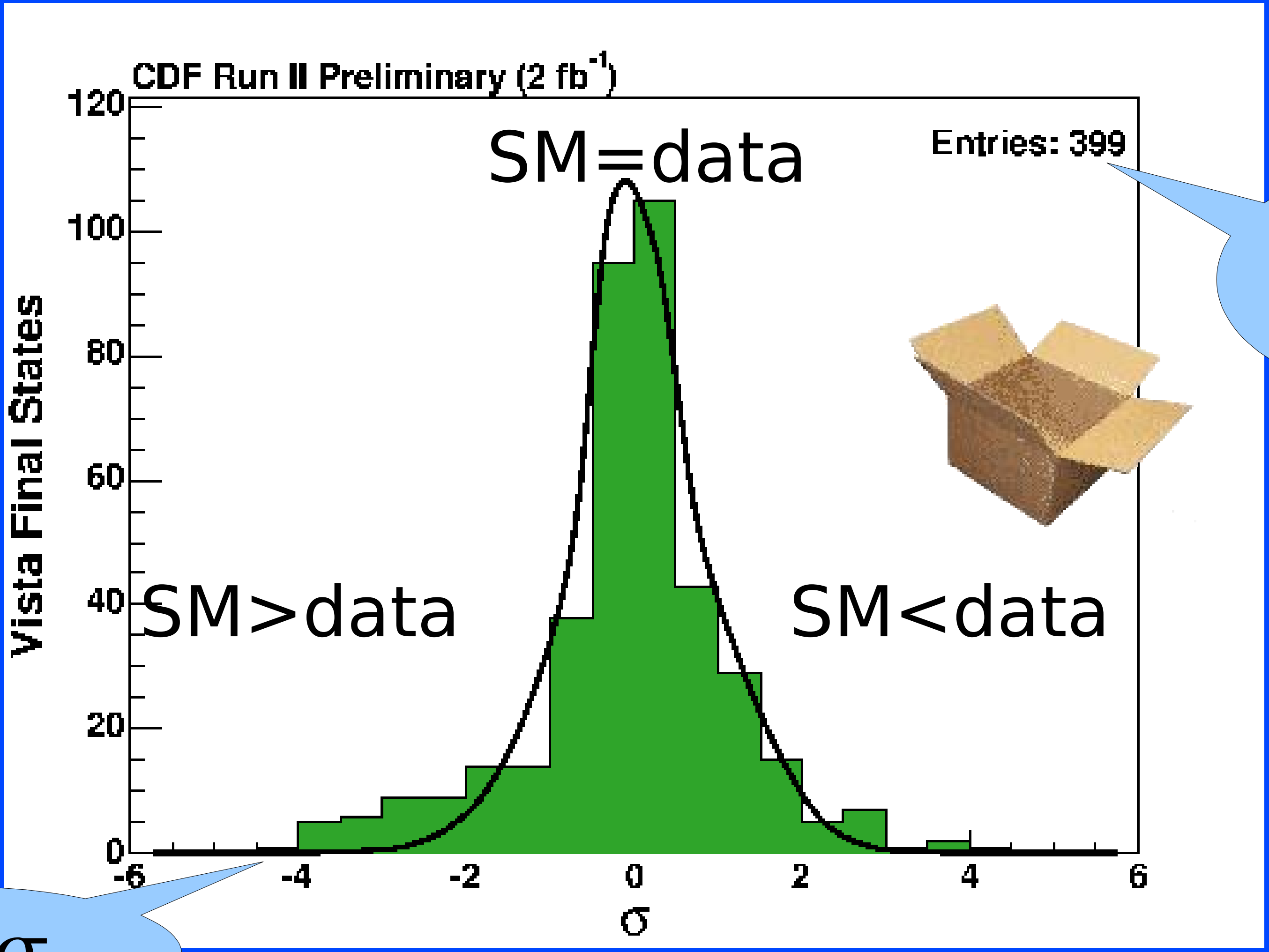
Final states defined by data

>10 events

ArXiv:0712.1311 CDF+...SM, GC, RC, CH, BK, SX

Vista final state normalizations

CDF RunII 2 fb^{-1}

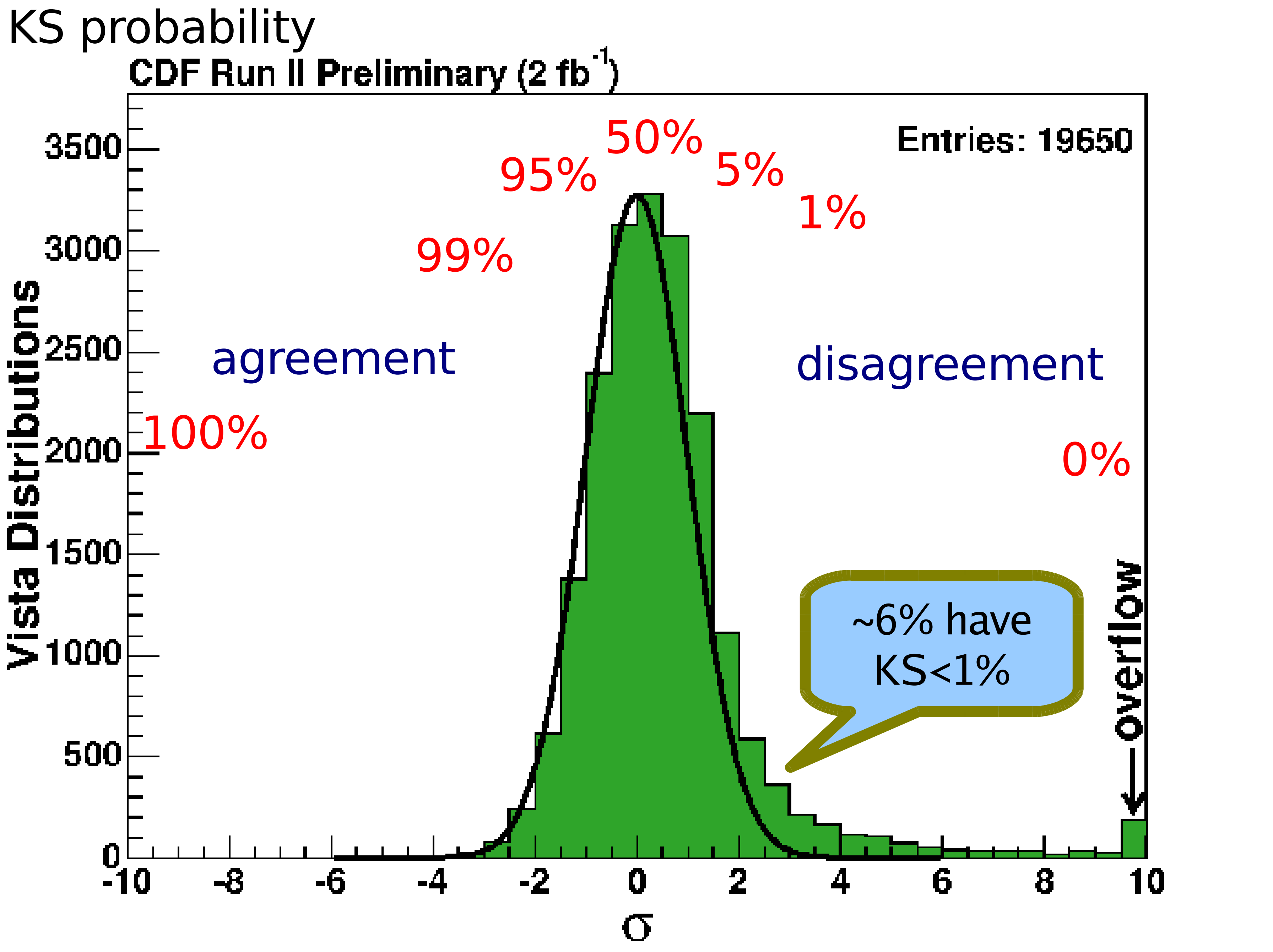


Trials factor

$2.7\,\sigma$

G. Choudalakis, R. Culbertson, C. Henderson, B, Knuteson, Si Xie

Vista kinematic shapes



Quantitative Results

Event counts are distributed as you expect when you look at 399 final states

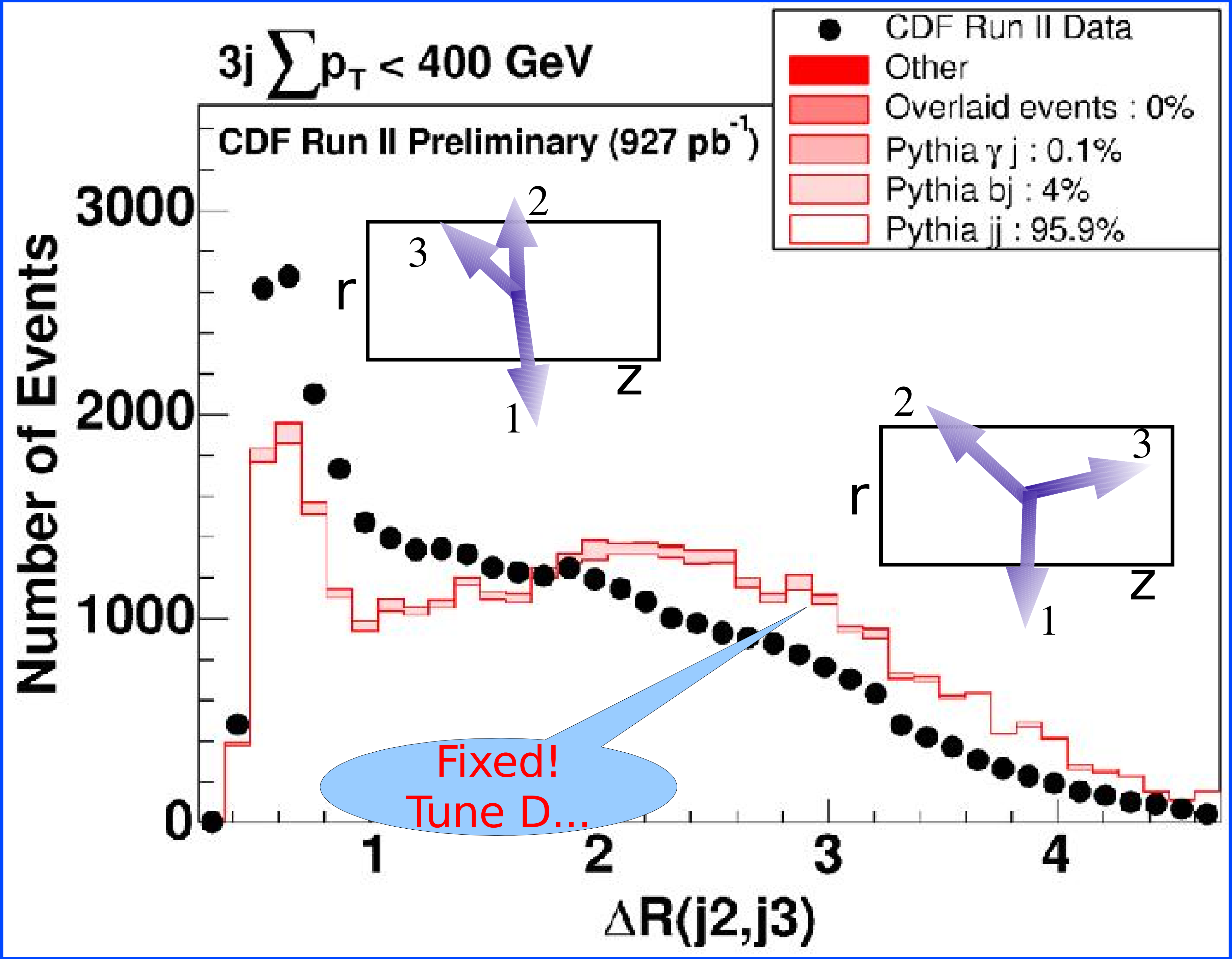
Largest discrepancy is a 2.7sigma deficit

Several % of all distributions disagree:

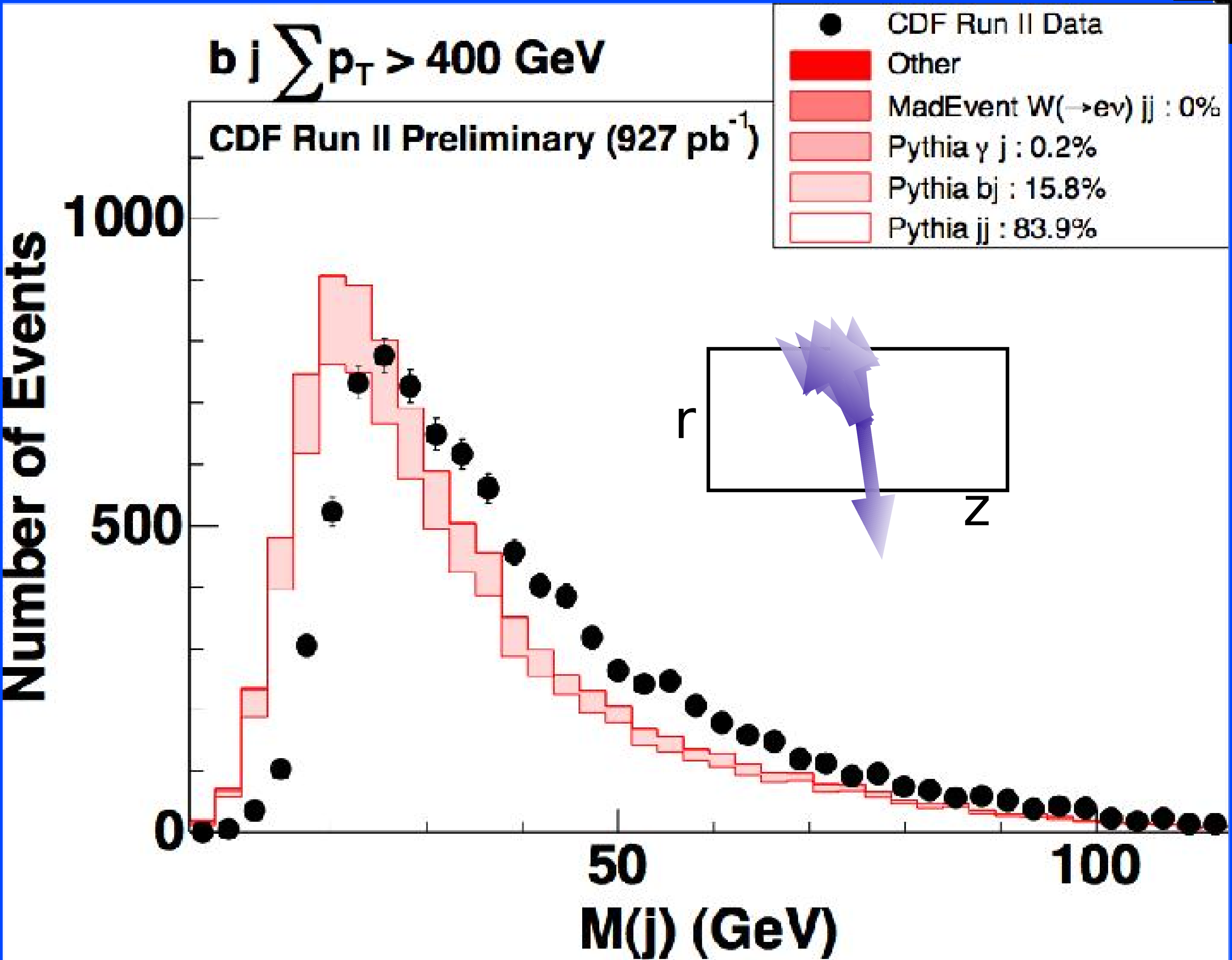
1% is typical of the systematic expected in event generators

about 6% of distributions have KS<1%, but there are many commonalities

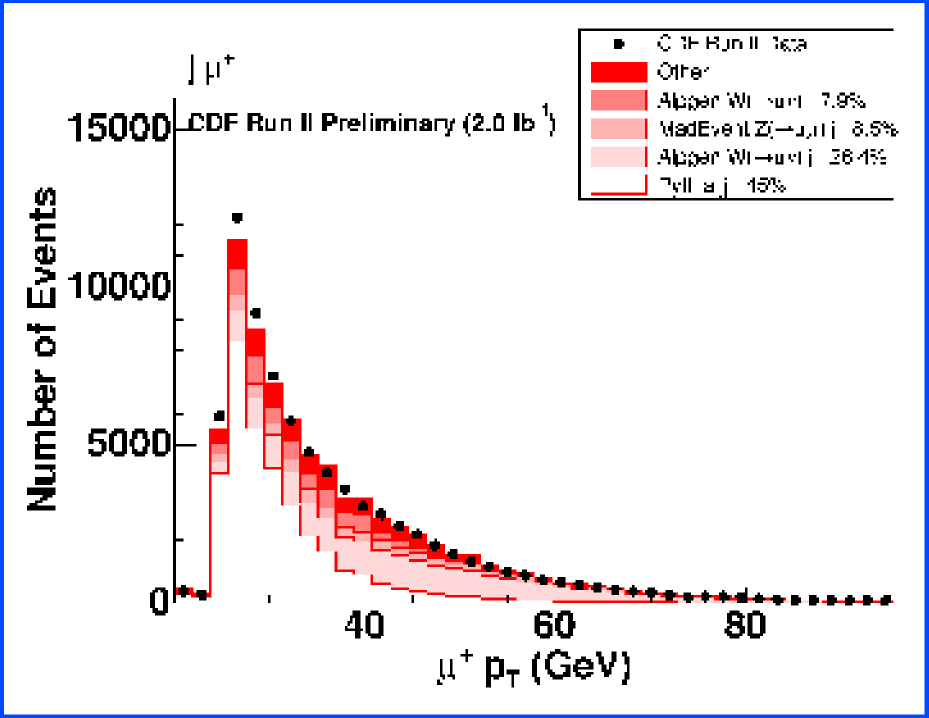
Sample discrepant distribution

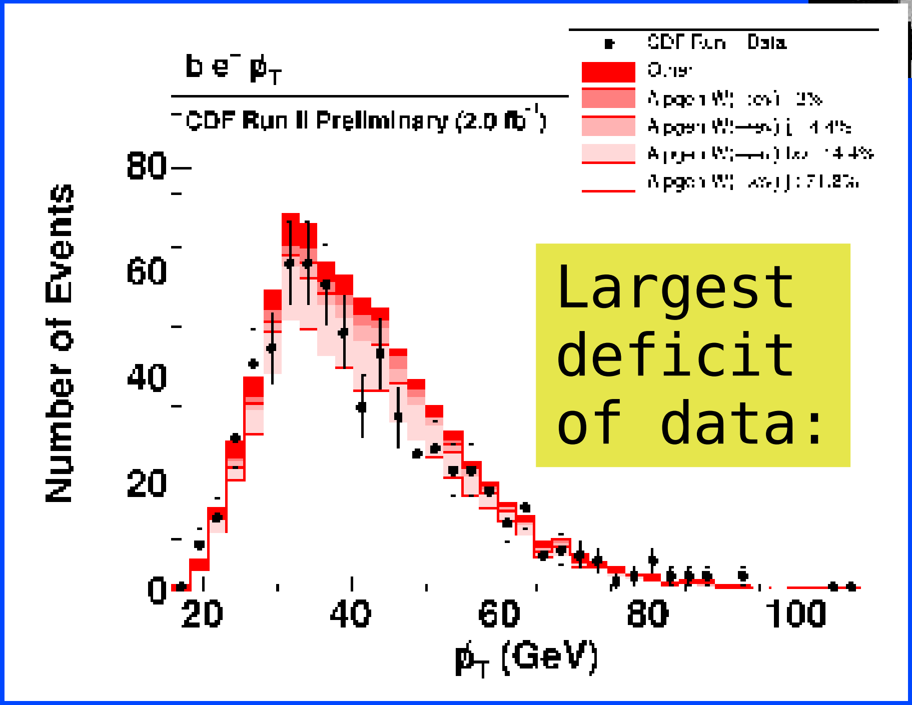


Related discrepant distribution

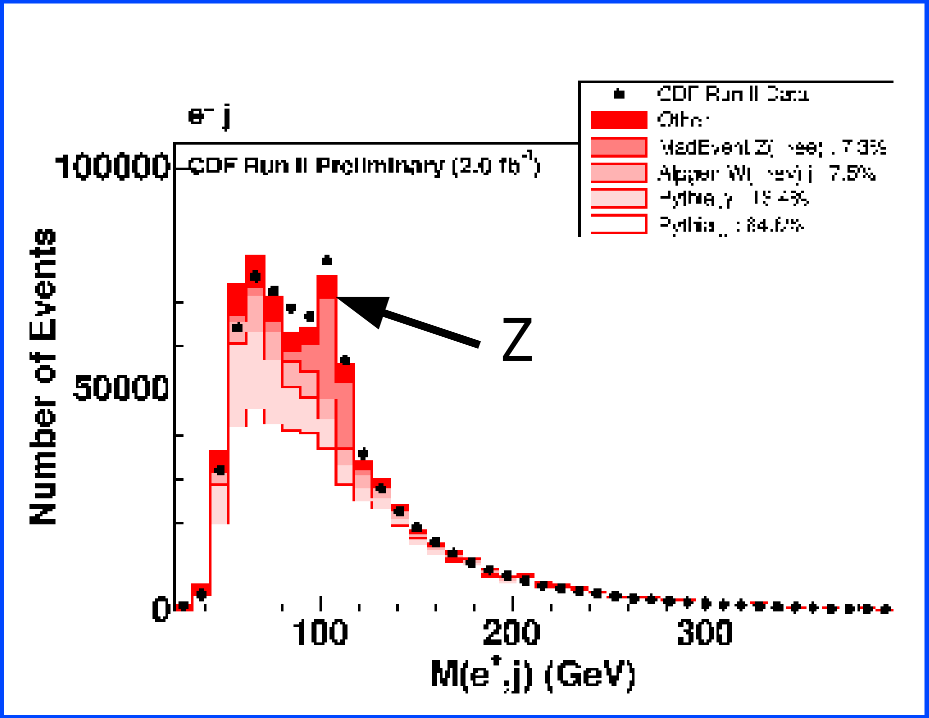


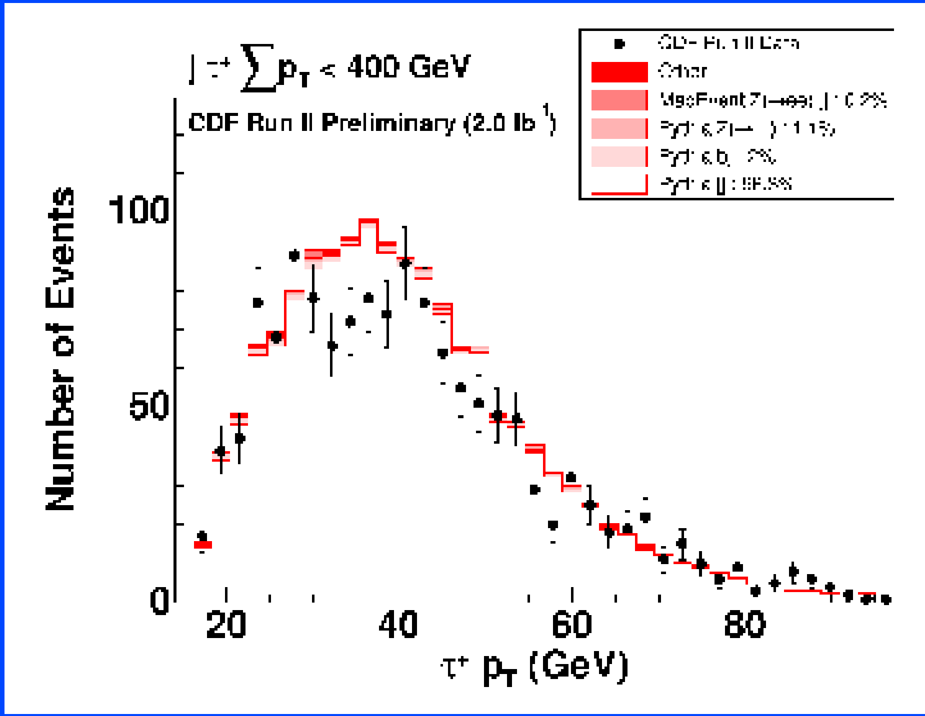
Many things described well!





Largest deficit of data:





Dissecting the SM cocktail

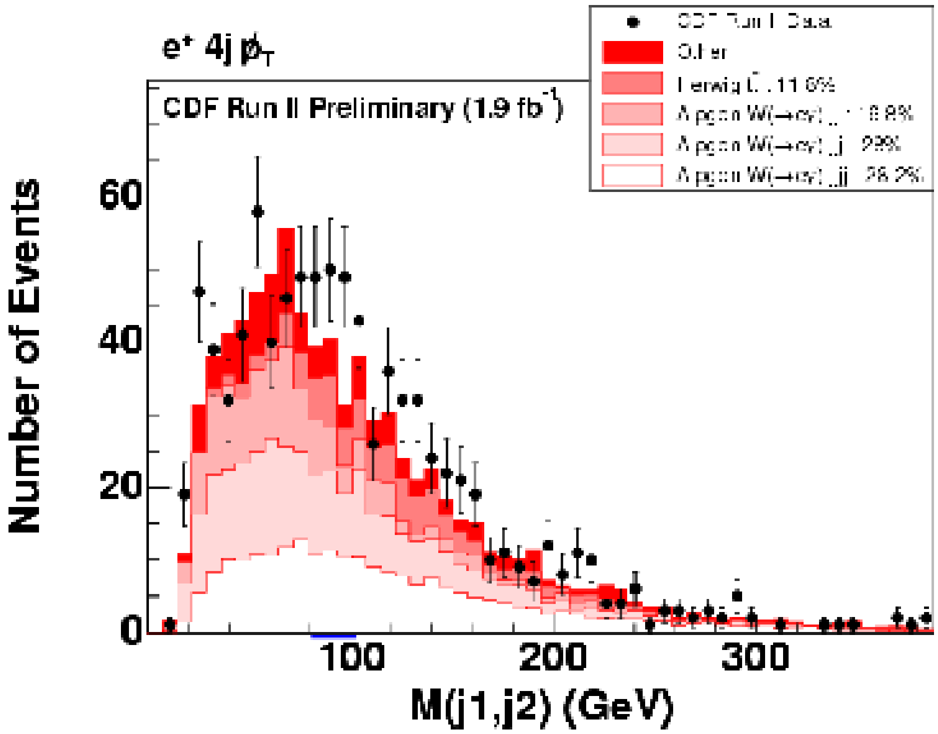
Much of the Monte Carlo is default Pythia/Herwig (simple processes + parton showers)

Some processes like W/Z/γ+jets combine Matrix Elements with parton showers

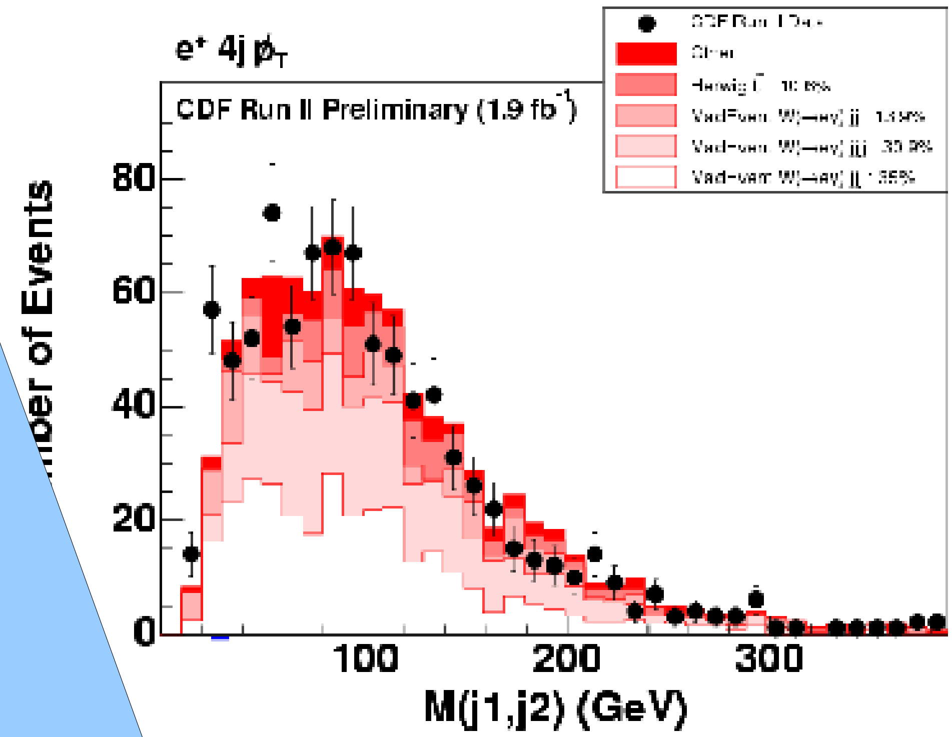
Such calculations are necessary for the LHC

We can remix our cocktail with different implementations of the Standard Model theory

Change W+4j model:Goodness of fit unchanged



MLM matching



SM matching

		Alpgen	SM
k-factor	W0j	1.379	1.452
k-factor	W1j	1.329	1.20
k-factor	W2j	2.007	1.23
k-factor	W3j	2.109	1.18

Relevant K-Factors

6M/6L1

K=NLO/LO

6M/6M

Process	Typical scales		Tevatron K-factor			LHC K-factor		
	μ_0	μ_1	$\mathcal{K}(\mu_0)$	$\mathcal{K}(\mu_1)$	$\mathcal{K}'(\mu_0)$	$\mathcal{K}(\mu_0)$	$\mathcal{K}(\mu_1)$	$\mathcal{K}'(\mu_0)$
W	m_W	$2m_W$	1.33	1.31	1.21	1.15	1.05	1.15
W+1jet	m_W	p_T^{jet}	1.42	1.20	1.43	1.21	1.32	1.42
W+2jets	m_W	p_T^{jet}	1.16	0.91	1.29	0.89	0.88	1.10
WW+jet	m_W	$2m_W$	1.19	1.37	1.26	1.33	1.40	1.42
$t\bar{t}$	m_t	$2m_t$	1.08	1.31	1.24	1.40	1.59	1.48
$t\bar{t}$+1jet	m_t	$2m_t$	1.13	1.43	1.37	0.97	1.29	1.10
$b\bar{b}$	m_b	$2m_b$	1.20	1.21	2.10	0.98	0.84	2.51
Higgs	m_H	p_T^{jet}	2.33	–	2.33	1.72	–	2.32
Higgs via VBF	m_H	p_T^{jet}	1.07	0.97	1.07	1.23	1.34	1.09
Higgs+1jet	m_H	p_T^{jet}	2.02	–	2.13	1.47	–	1.90
Higgs+2jets	m_H	p_T^{jet}	–	–	–	1.15	–	–

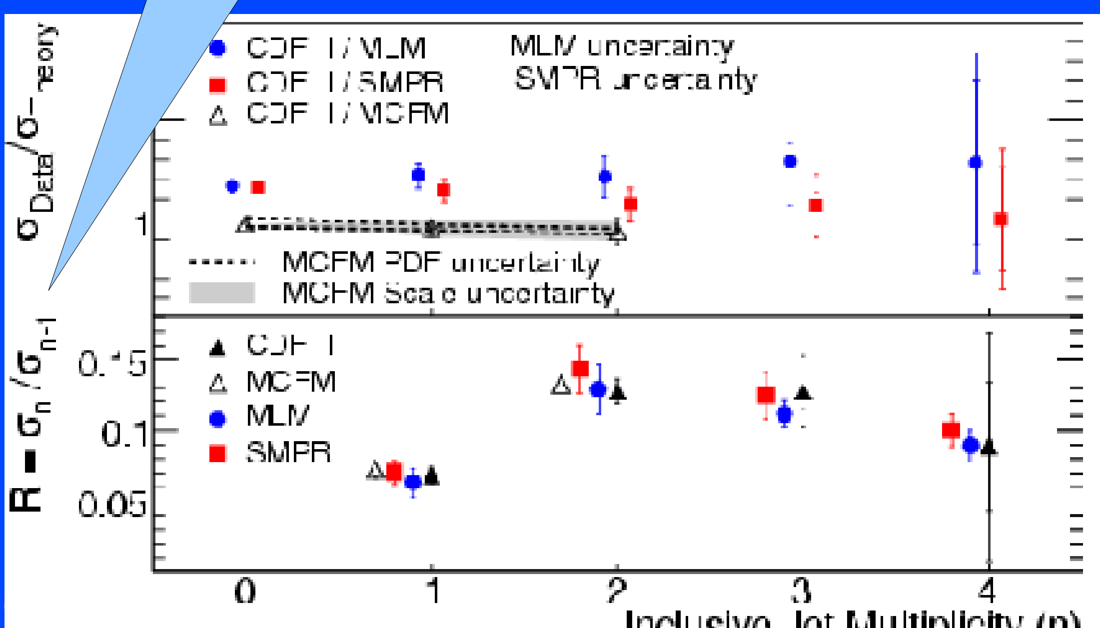
ArXiv:0711.4044 CDF...(SM)

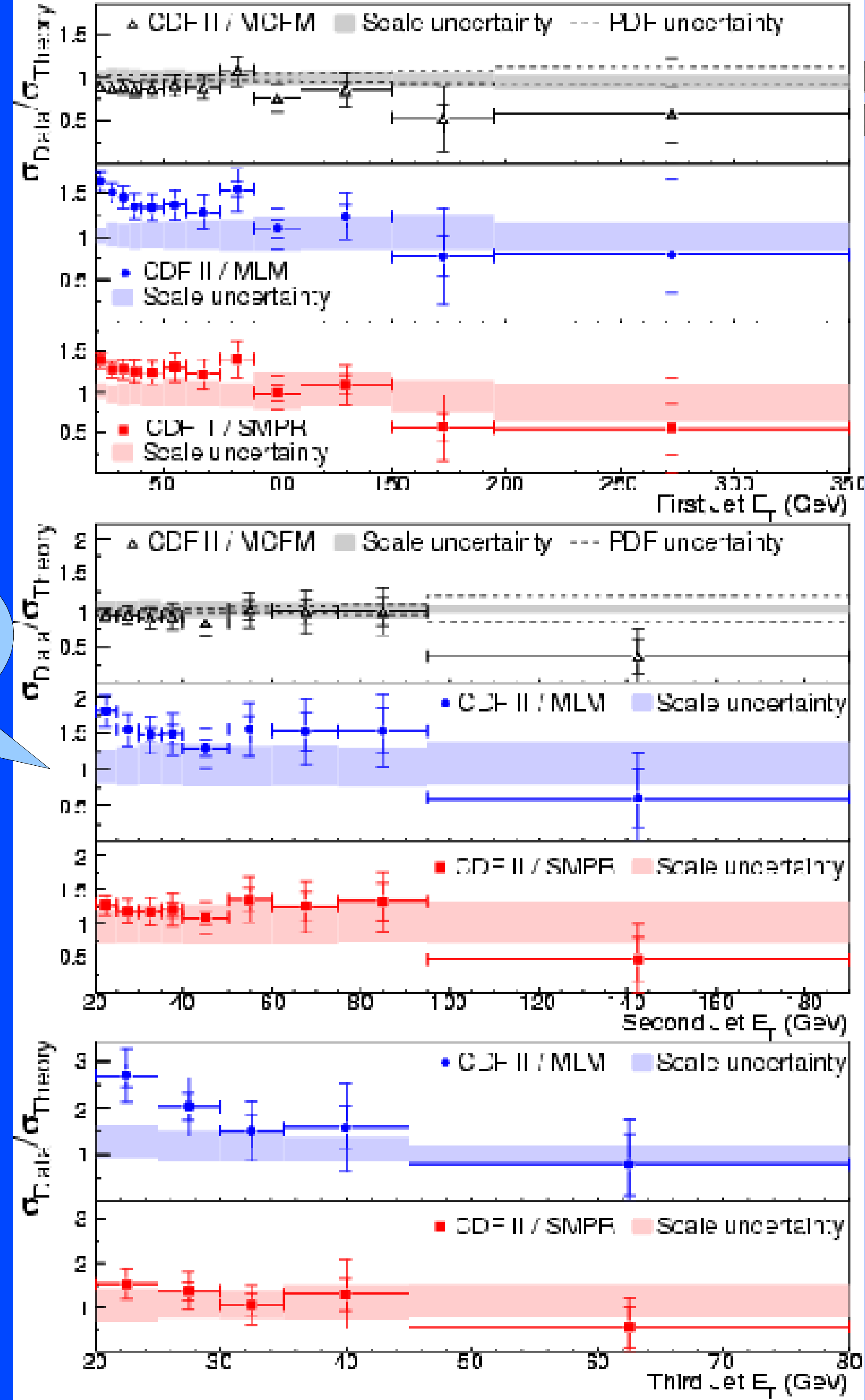
Traditional Analysis

Data corrected (unfolded)
back to the particles
(this it the output of Pythia)

Comparison of relative event counts

Comparison of relative shapes





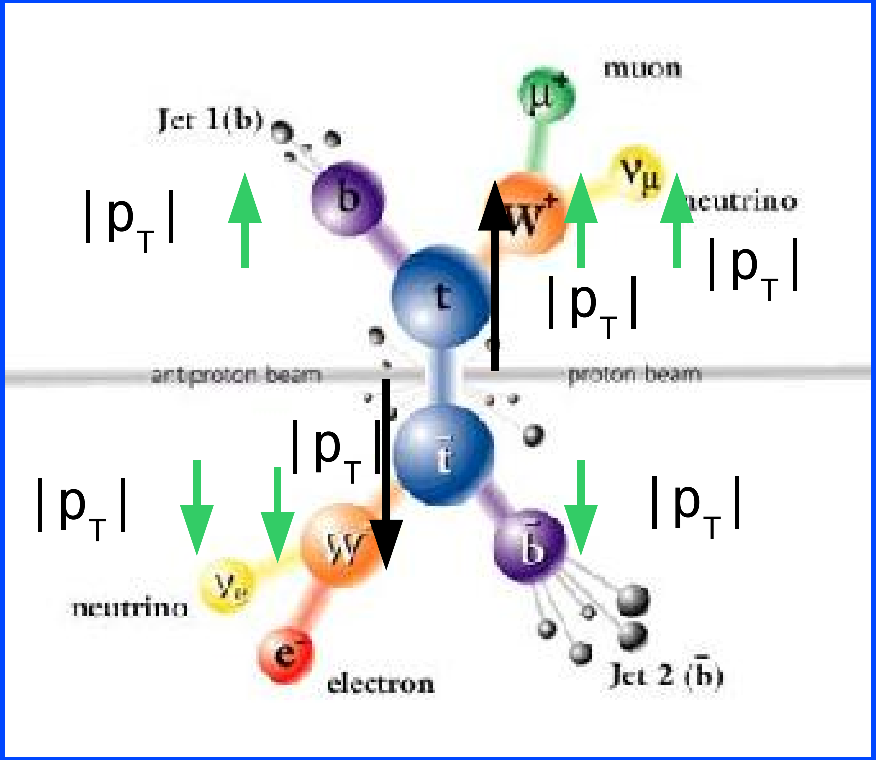
“... All distributions show good agreement with the data ...”

#3: Sleuth, a model independent search strategy for new physics

Exclusive final states

Large $\sum|p_T|$

An excess

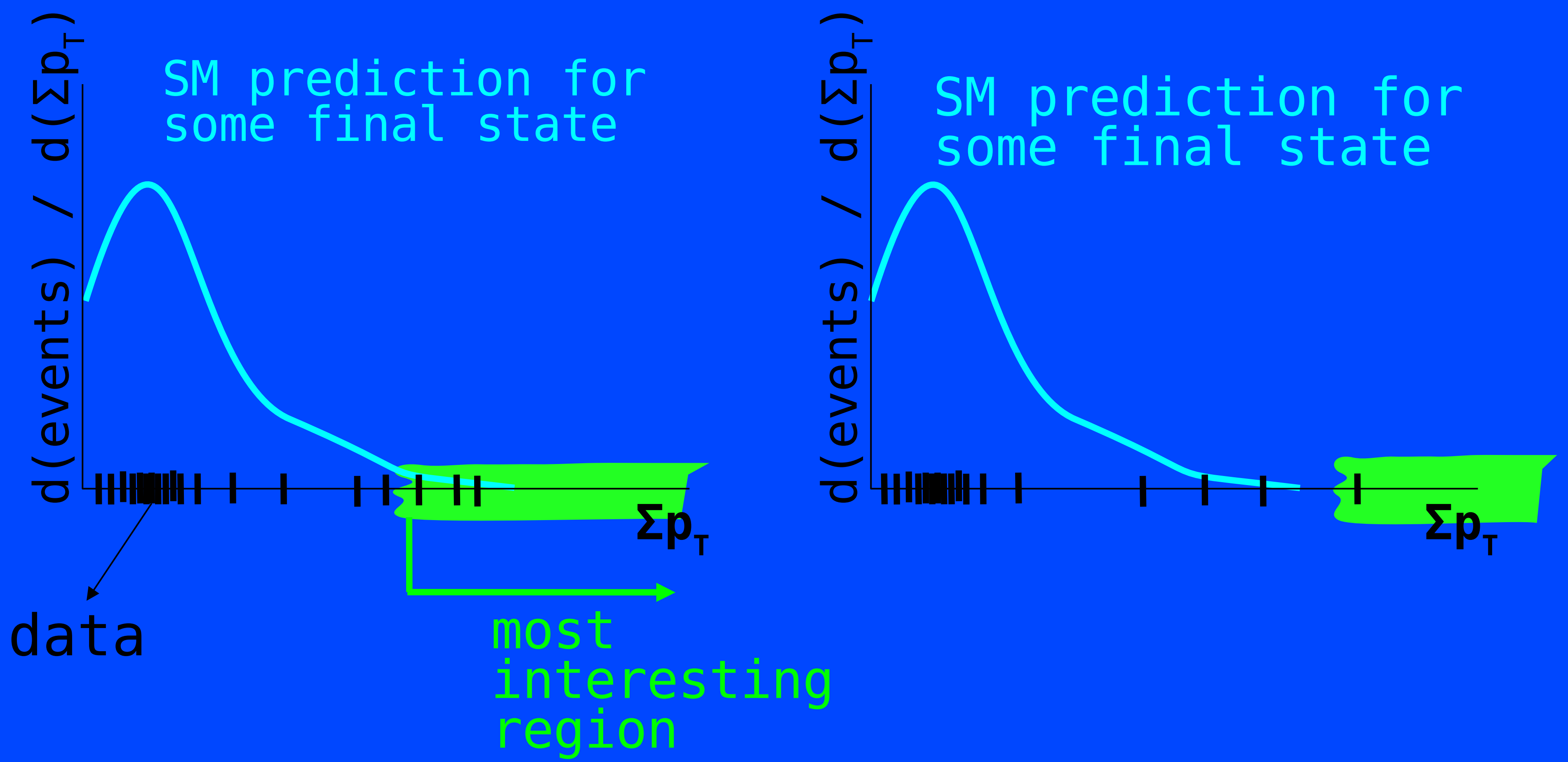


Rigorously compute the trials factor associated with looking everywhere

$$\int_{0001001}^{today} d(hep-ph)(prediction)$$

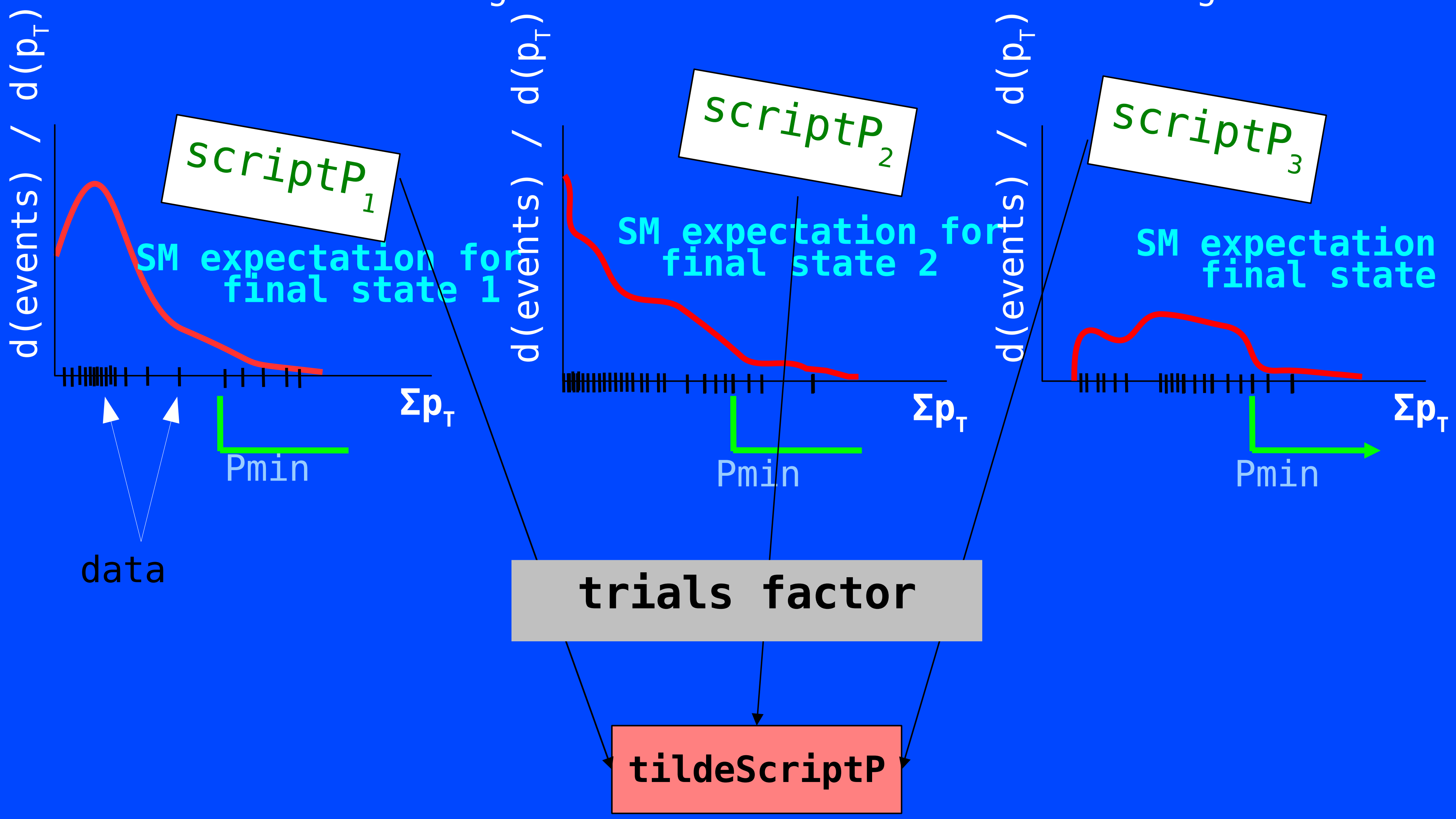
Goal of Sleuth

Identify statistically significant excess of data in the high-Σp_T tails.



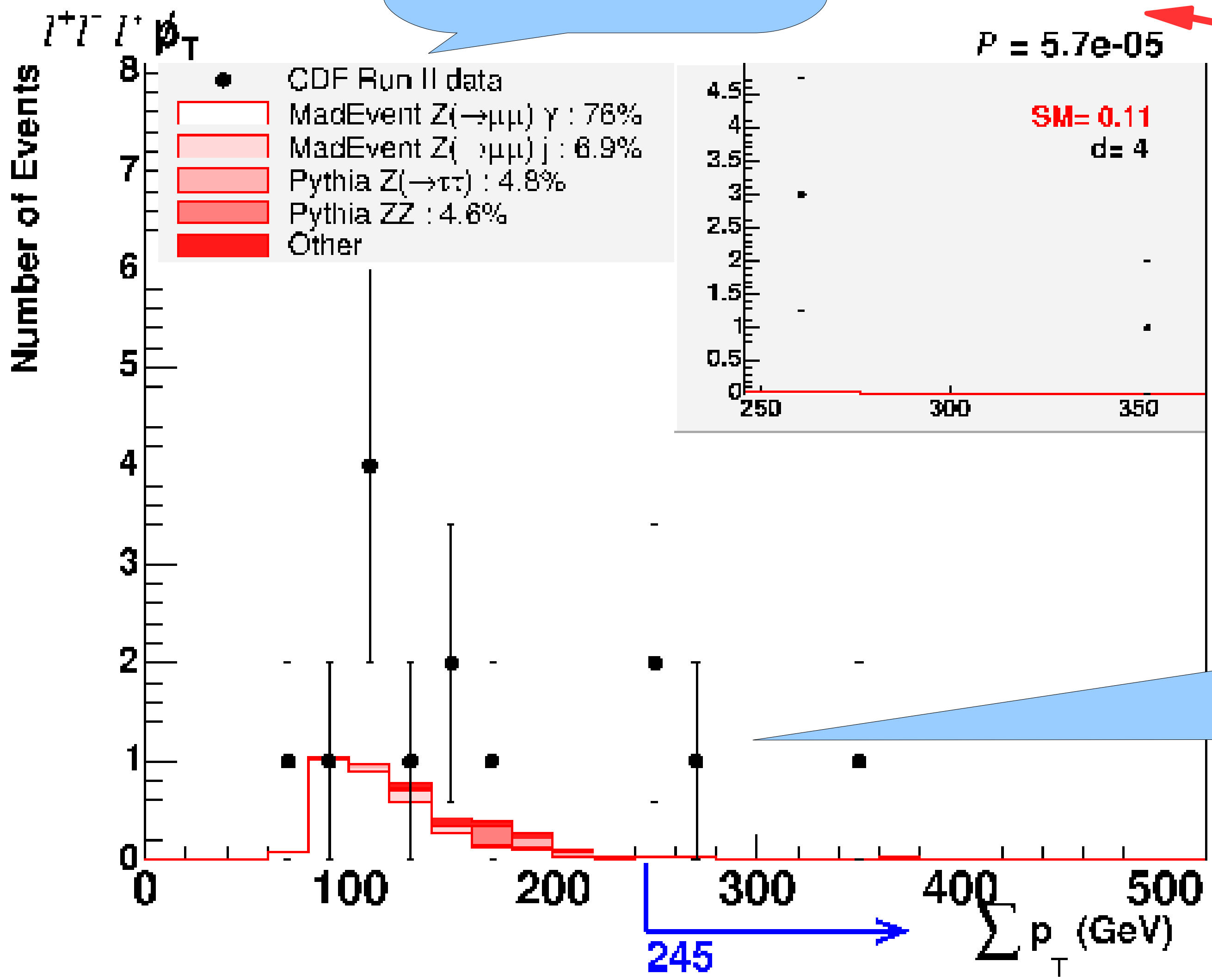
Recap: Sleuth Algorithm

ScriptP = % of pseudo-experiments where this final state has any tail more interesting than the actual most interesting one.



TildeScriptP = % of pseudo-experiments that would produce any tail in any final state, that would be more interesting than *the* most interesting tail actually observed.

W+Z
removed



ScriptTildeP
=.01
=2.6sigma

Vista
“discovery”
of W+Z

Sleuth @CDFII result

$$\tilde{\mathcal{P}} = 0.08$$

8% of pseudo-experiments should be as interesting

(top 5)

CDF Run II Preliminary (2.0 fb^{-1})

SLEUTH Final State	$\mathcal{P}$
$\ell^+\ell'^+$	0.00055
$\ell^+\ell'^+\not{p}jj$	0.0021
$\ell^+\ell'^+\not{p}$	0.0042
$\ell^+\ell^-\ell'\not{p}$	0.0047
$\ell^+\tau^+\not{p}$	0.0065

No significant excess

This does not prove no new physics!

CDF Run II (1 fb^{-1})

Sleuth @CDFIIa result

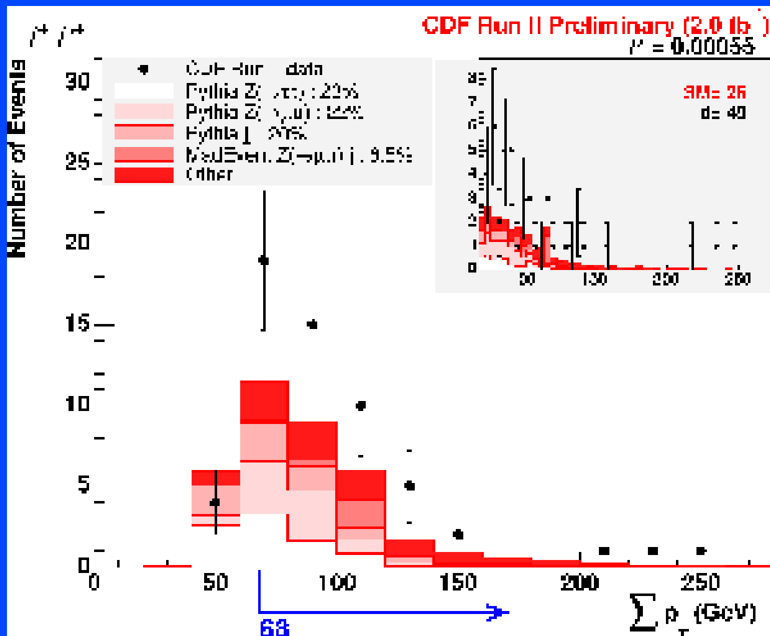
$$\tilde{\mathcal{P}} = 0.46$$

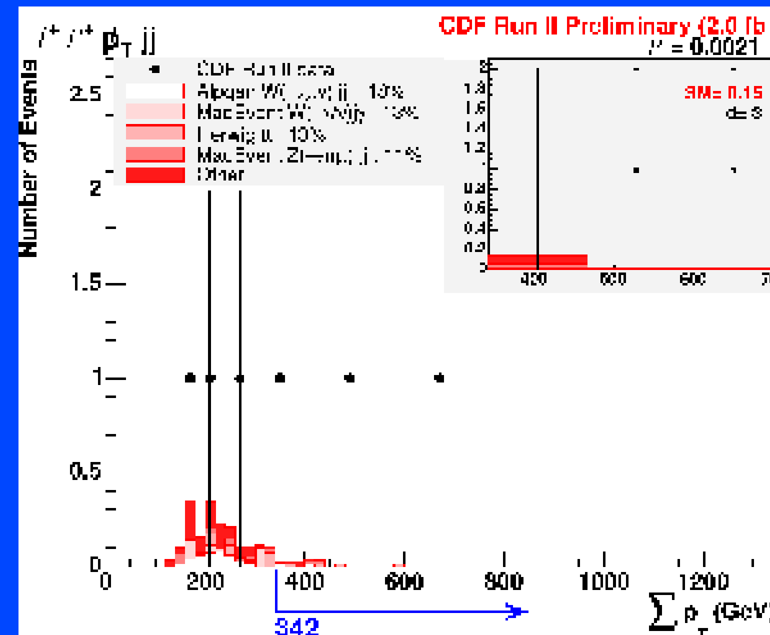
SLEUTH Final State	$\mathcal{P}$
$b\bar{b}$	0.0055
$j\,\not{p}$	0.0092
$\ell^+\ell'^+\,\not{p}jj$	0.011
$\ell^+\ell'^+\,\not{p}$	0.016
$\tau\,\not{p}$	0.016

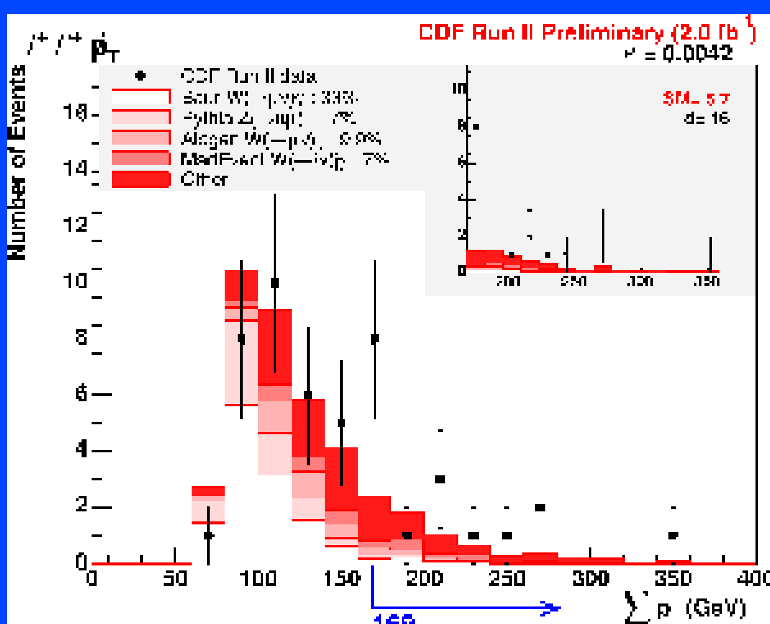
CDF Run II Preliminary (2.0 fb^{-1})

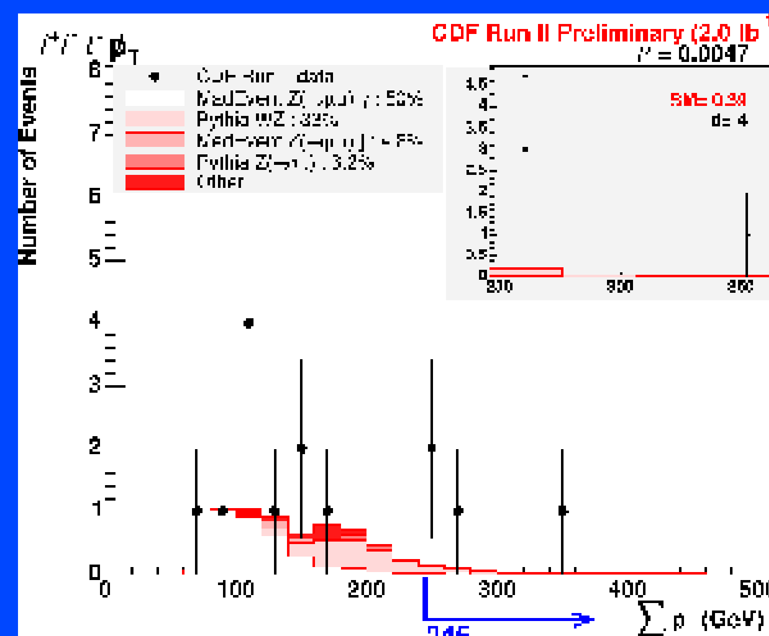
SLEUTH Final State	$\mathcal{P}$
$\ell^+\ell'^+$	0.00055
$\ell^+\ell'^+\,\not{p}jj$	0.0021
$\ell^+\ell'^+\,\not{p}$	0.0042
$\ell^+\ell^-\ell'\,\not{p}$	0.0047
$\ell^+\tau^+\,\not{p}$	0.0065

http://www-cdf.fnal.gov/physics/exotic/r2a/20080228.vista_sleuth/publicPage.html









The greatest limitation to this blind new physics search is mis-modeling of backgrounds

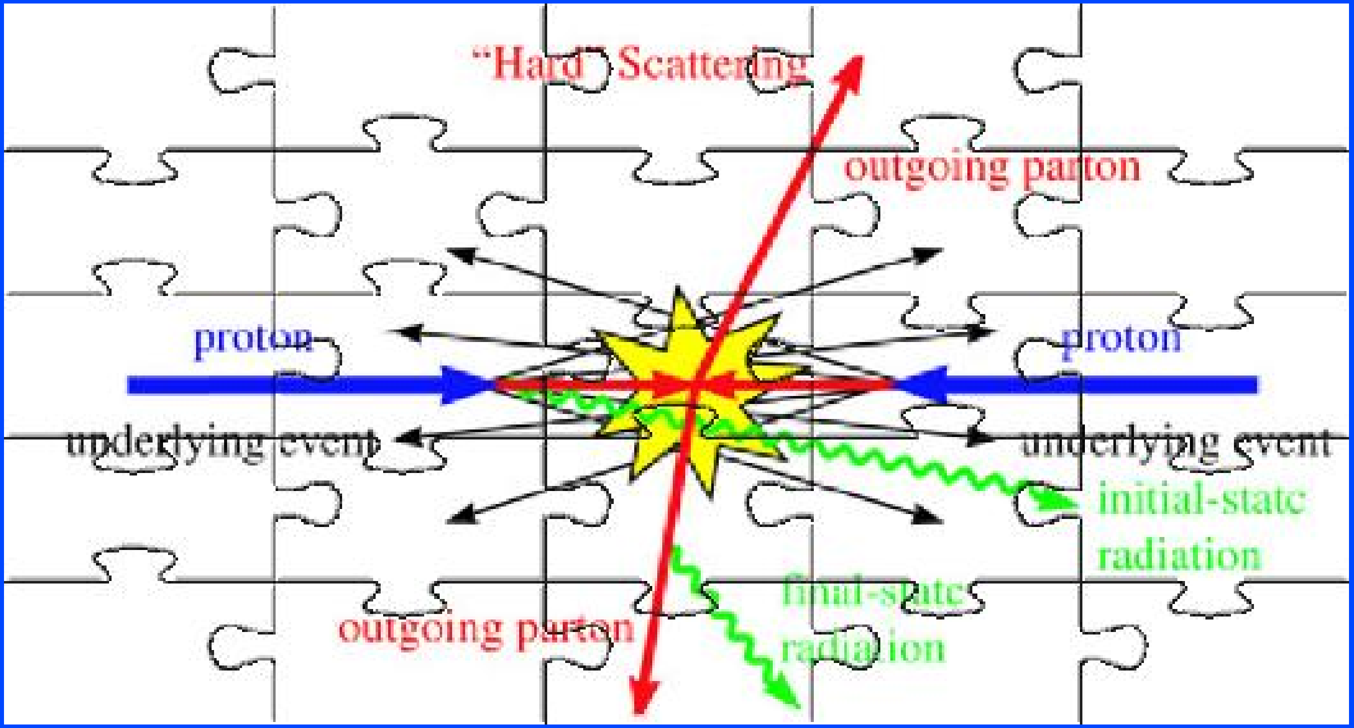
Note: this analysis does NOT incorporate PDF, showering uncertainties:

these are “fit” using correlations between different final states (e.g. K-factors from data)

What does this mean for the LHC?

- Before: Gave 3 arguments that we model physics @ high-Pt well
- Now: this is not entirely relevant
  - @LEP & @TeV, we mainly study quarks
  - Focus on things we don't do well
- Later: why this doesn't matter much for 100 pb^-1

What do we expect at the LHC?



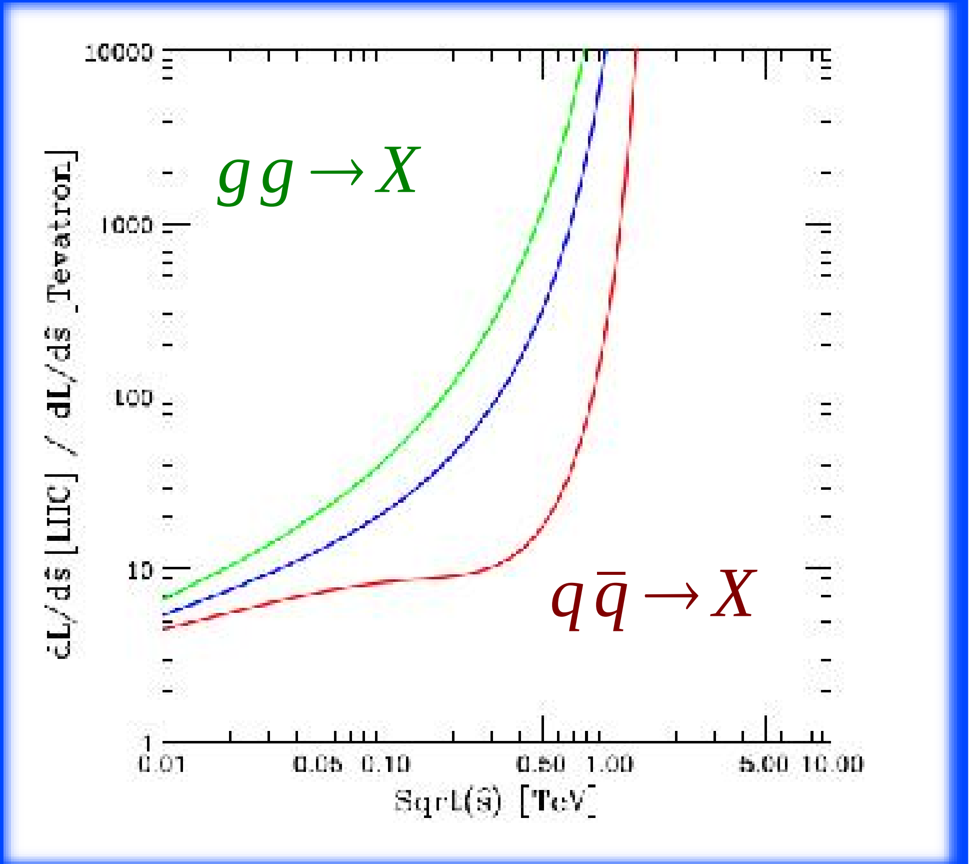
How much does the $t\bar{t}$ cross section change from the Tevatron to the LHC?

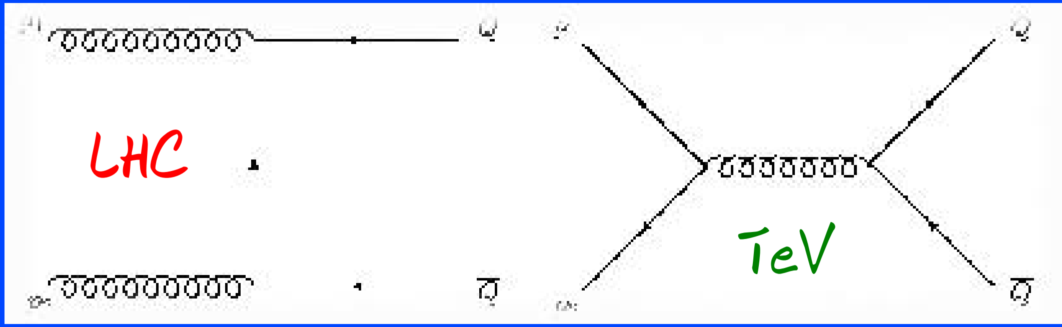
10x

100x [Kidonakis]

500x

Partonic luminosity LHC/TeV2



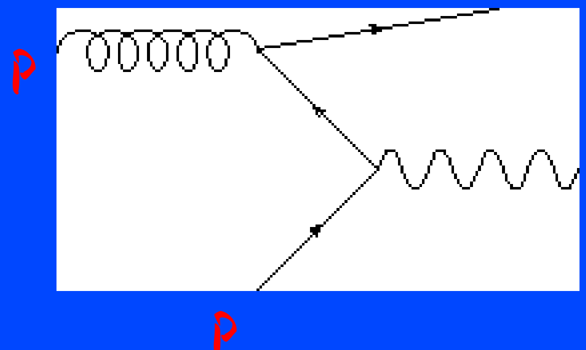


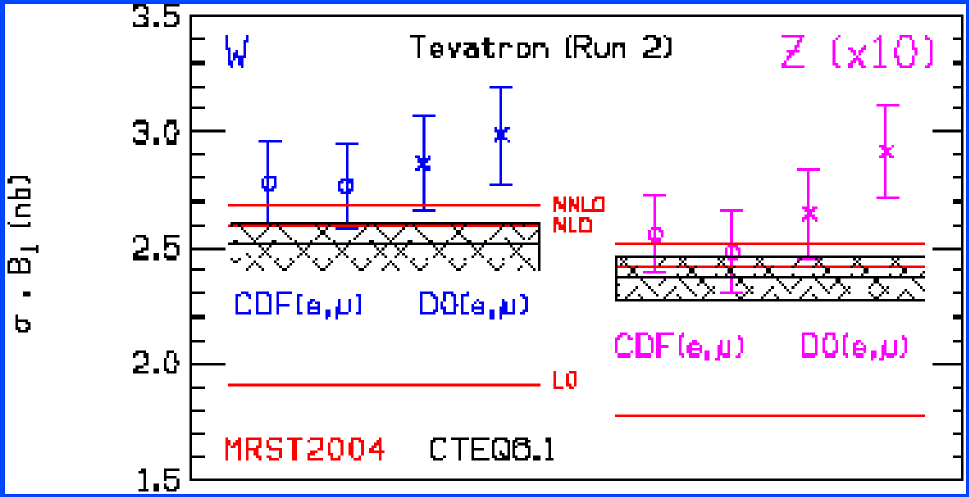
How much does the $\tilde{\chi}^{+}\tilde{\chi}^{-}$ (m=200 GeV) cross section change from the Tevatron to the LHC?

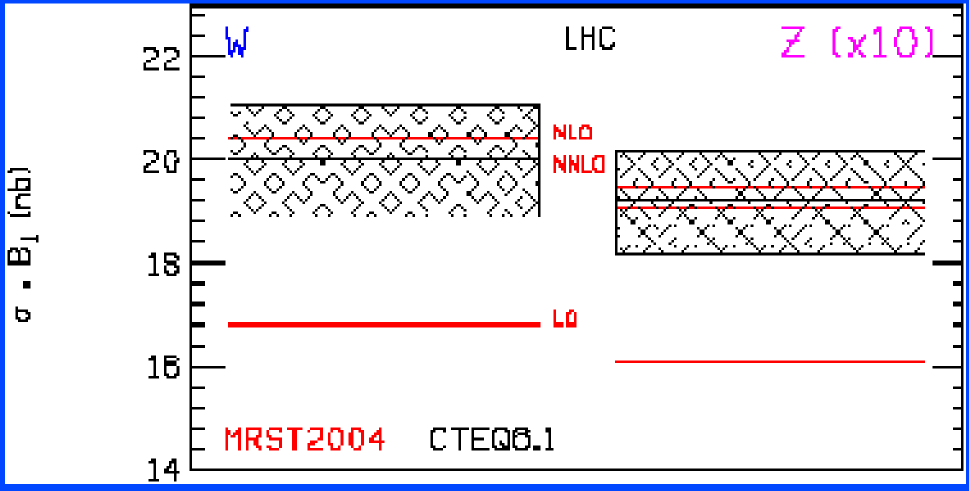
10x [Pythia]

100x

500x







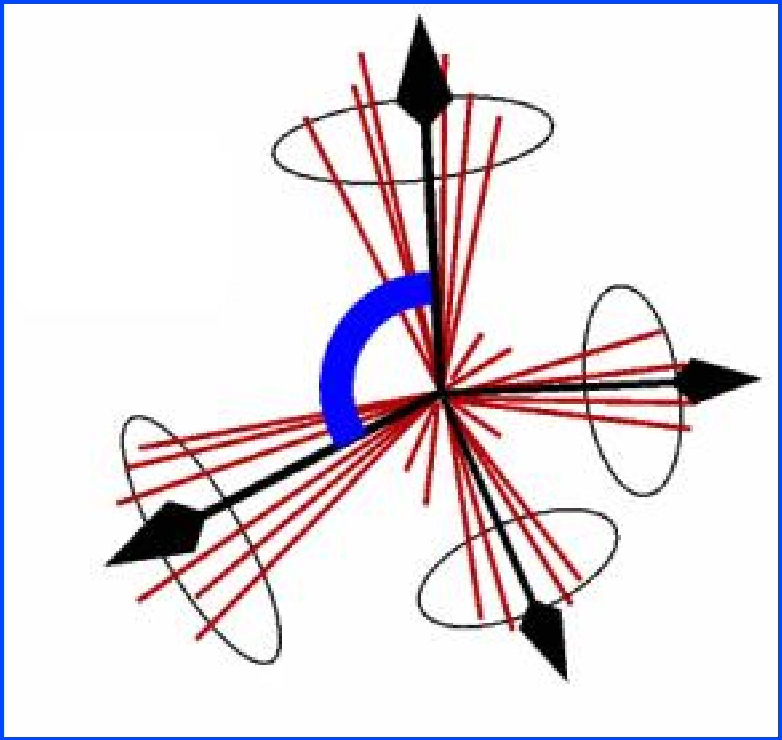
How much does the W+4j cross section change from the Tevatron to the LHC?

$k_{Tj} > 20\,GeV$

10x

100x

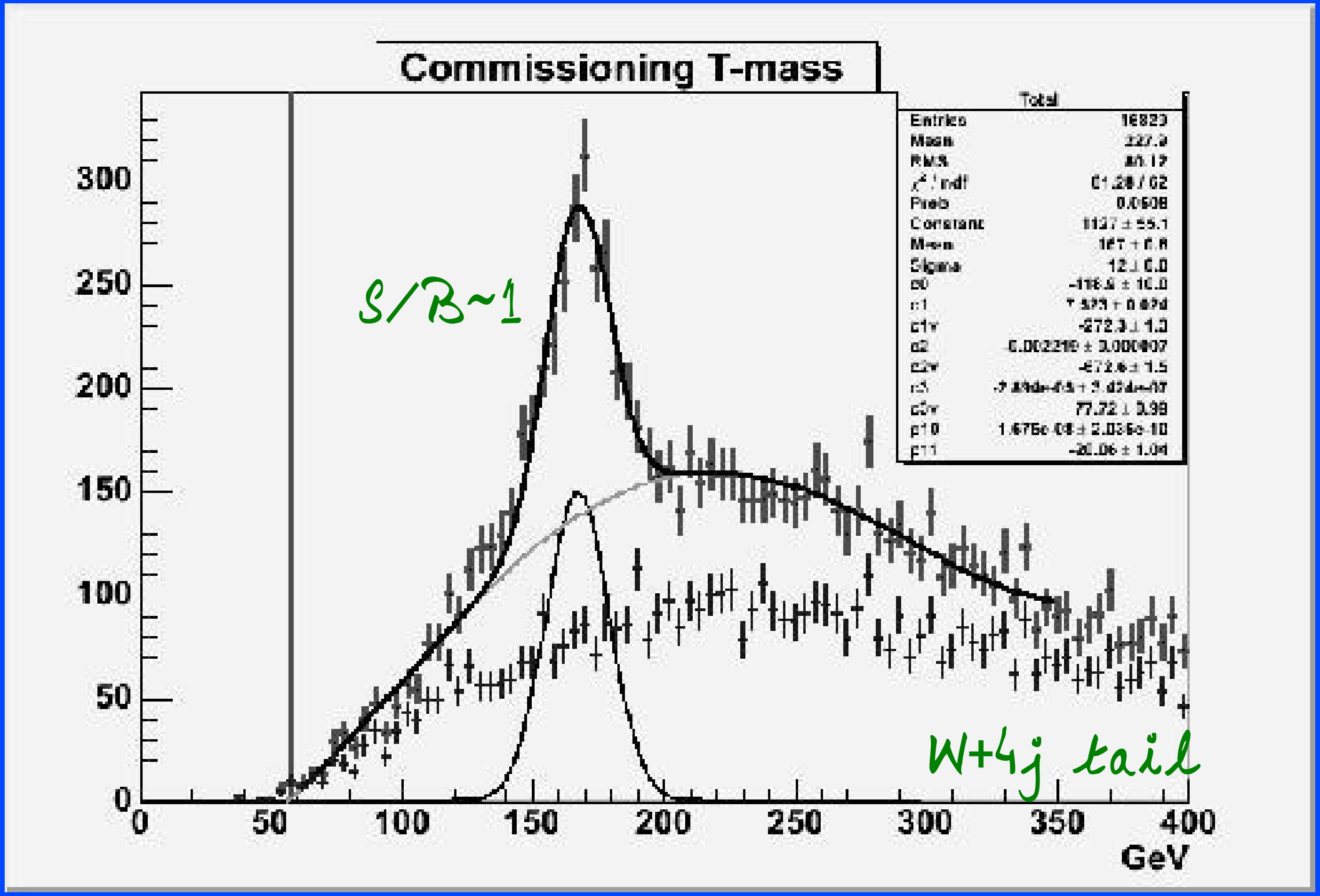
500x



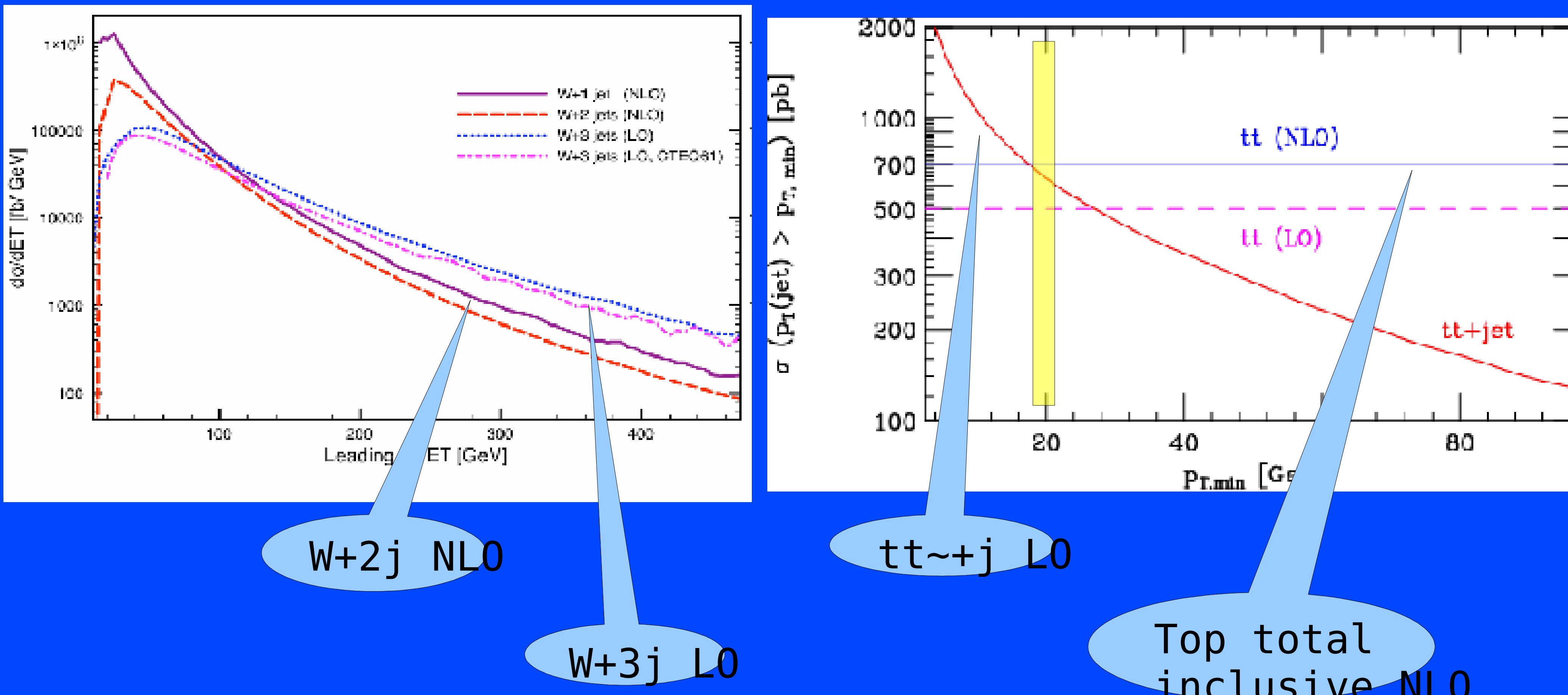
[MadEvent]

Top vs W (ATLAS study)

M. Barisonzi

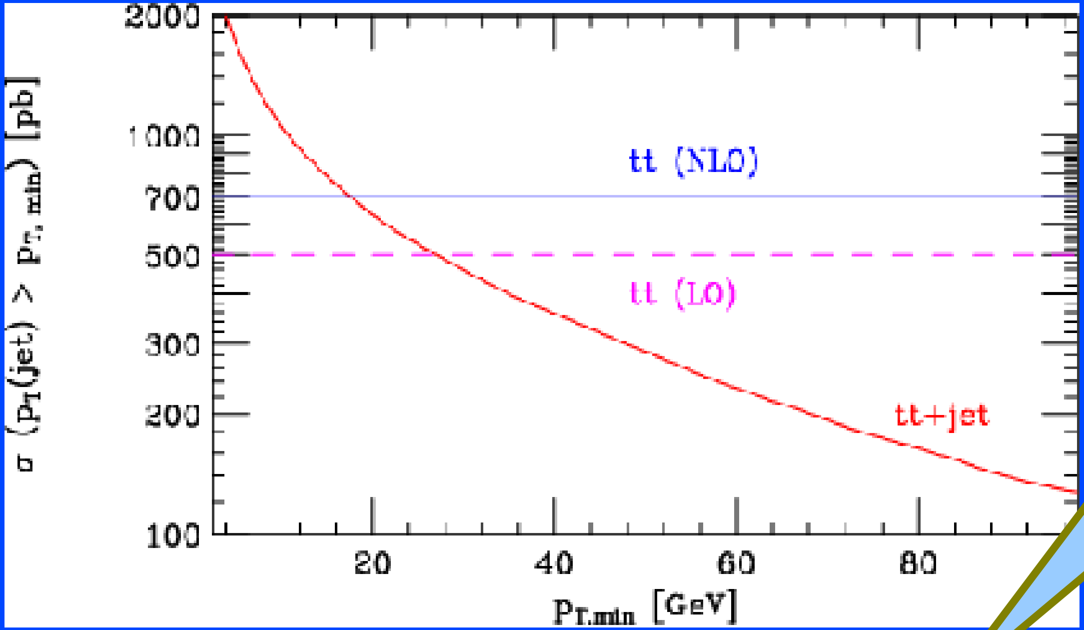


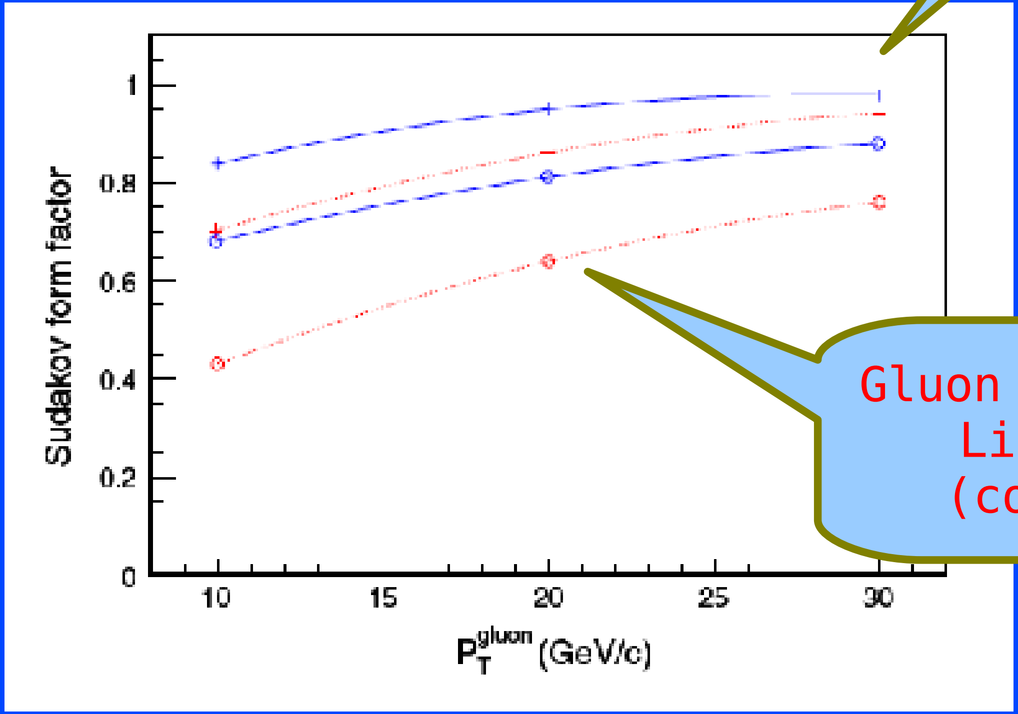
The LHC: a very *jetty* place



Has perturbation theory gone wrong?

Sudakov form factors for Top



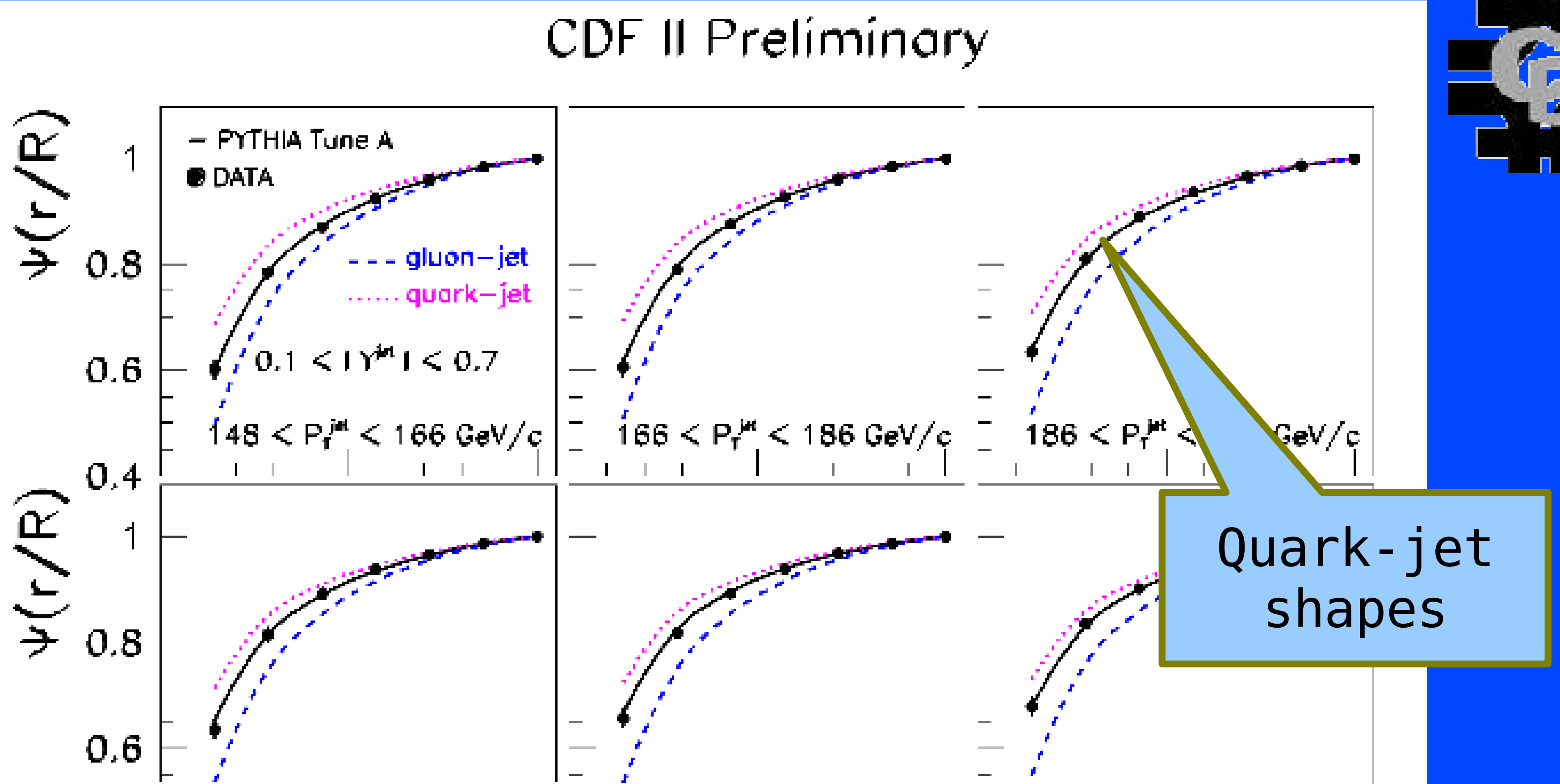


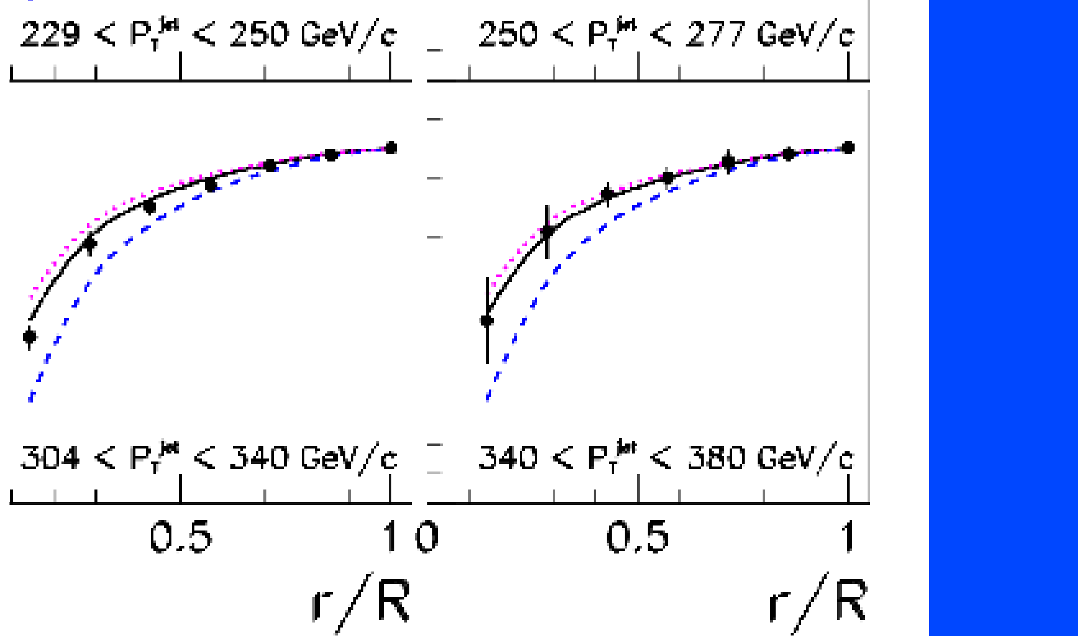
Quark @TeV2 radiates
Less (color=4/3)

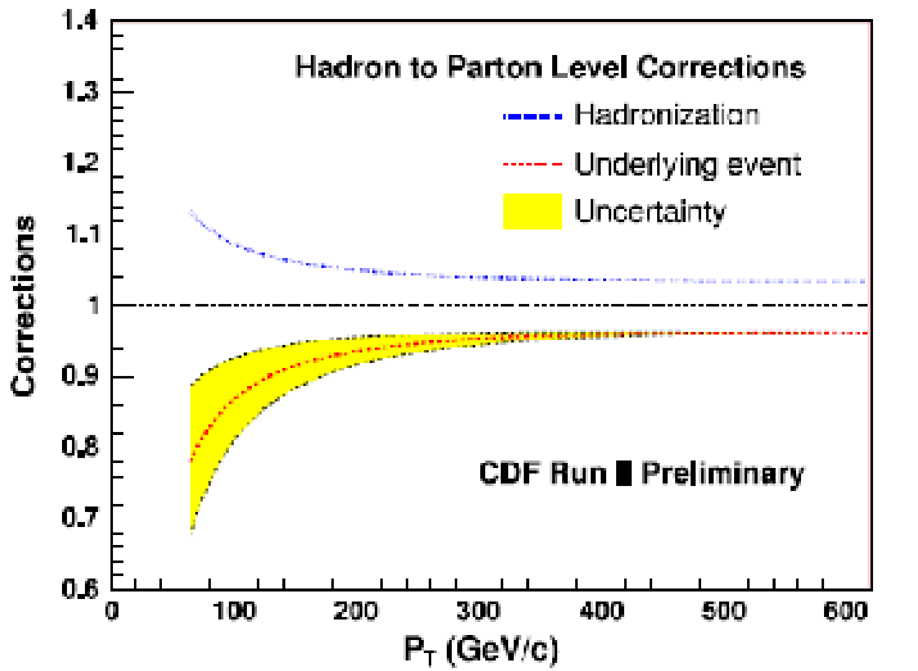
Gluon @LHC radiates
Like q+qbar
(color=3~8/3)

Greatest Concerns in TeV → LHC Extrapolation

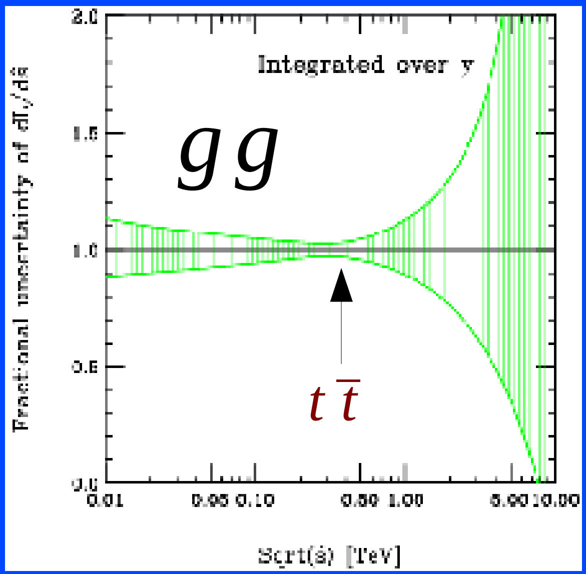
- Exploring new kinematic regimes
  - Not so much an issue, except UE, small x
- Complicated topologies
- Studying gluons instead of quarks


CDF II Preliminary
PYTHIA Tune A
DATA
gluon−jet
quark−jet
0.1 < |Y^jet| < 0.7
148 < P_T^jet < 166 GeV/c
166 < P_T^jet < 186 GeV/c
186 < P_T^jet < GeV/c
Ψ(r/R)
Quark-jet shapes


229 < P_T^jet < 250 GeV/c
250 < P_T^jet < 277 GeV/c
304 < P_T^jet < 340 GeV/c
340 < P_T^jet < 380 GeV/c
r/R


Hadron to Parton Level Corrections
Hadronization
Underlying event
Uncertainty
CDF Run II Preliminary
Corrections
P_T (GeV/c)

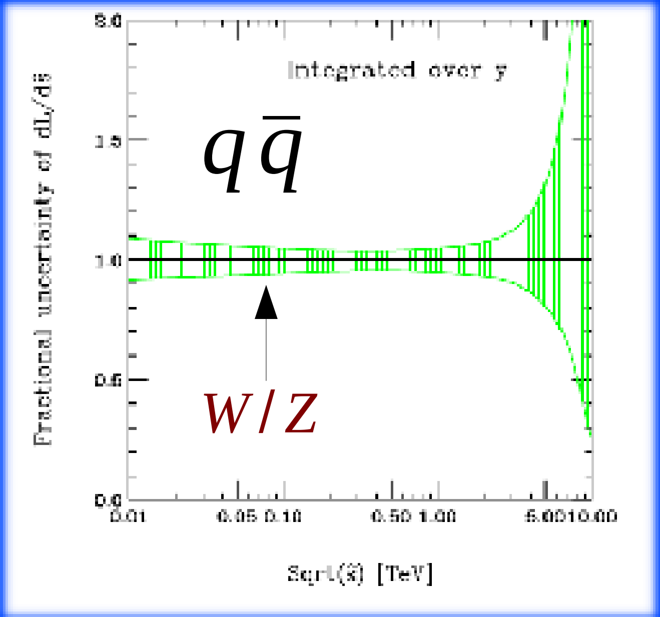
PDF uncertainties at the LHC



Under 1 TeV, PDF lumi known to 10%

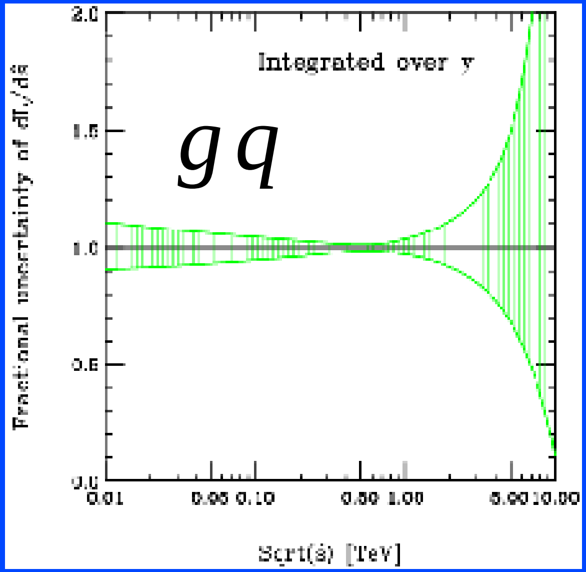
Need similar precision in theory calculations

Limits when LHC data will impact PDF fits



Pdf uncertainties for W/Z cross sections are not the smallest

Top uncertainty is of the same order as W/Z production



Large PDF uncertainty:
final state likely not well-studied

Small PDF uncertainty:
initial state known, but not necessarily final state

Topological overlap

W+4 partons			
TEVATRON		LHC	
Graph	Cross Sect (fb)	Graph	Cross Sect (pb)
Sum	1035.004	Sum	577.948
ug_e+vedggg	112.250	gu_e+vedggg	89.815
gux_e-vexdxggg	112.040	ug_e+vedggg	89.603
uux_e-vexudxgg	112.010	gd_e-vexuggg	45.522
uux_e+veuxdgg	111.900	dg_e-vexuggg	45.342
dux_e-vexddxgg	46.423	uu_e+veudgg	34.174
udx_e+veuuxgg	46.388	dxg_e+veuxggg	15.346
dux_e-vexuuxgg	46.349	gdx_e+veuxggg	15.341
udx_e+veddxgg	46.330	uxg_e-vexdxggg	10.868
gdx_e+veuxggg	40.234	gux_e-vexdxggg	10.866
dg_e-vexuggg	40.122	gg_e+veuxdgg	9.920
udx_e+vegggg	30.906	gg_e+vescxgg	9.907
dux_e-vexgggg	30.867	gg_e-vexsxcgg	9.907
ddx_e-vexudxgg	15.189	gg_e-vexudxgg	9.842
ddx_e+veuxdgg	15.171	du_e+veddgg	8.903
...	...	...	...

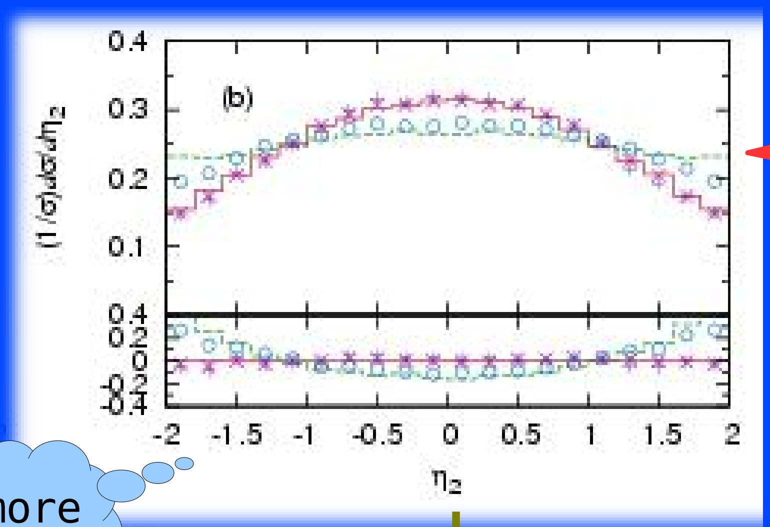
hep-ph/0706.2569v2

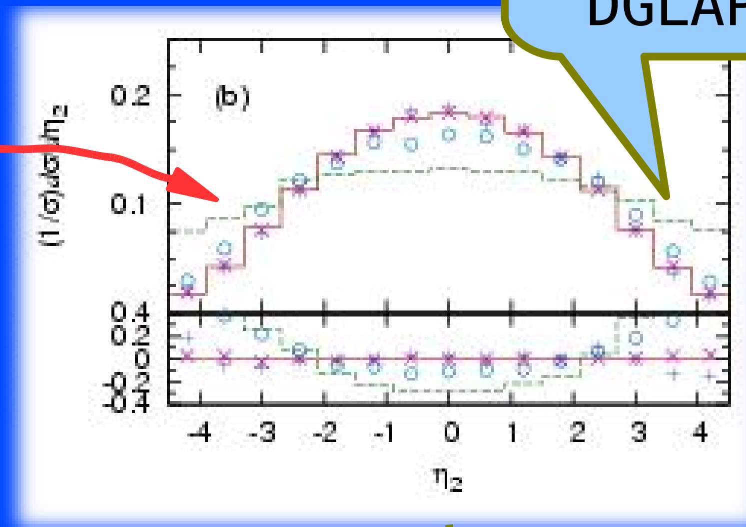
W+jets

Eta (2nd Jet)

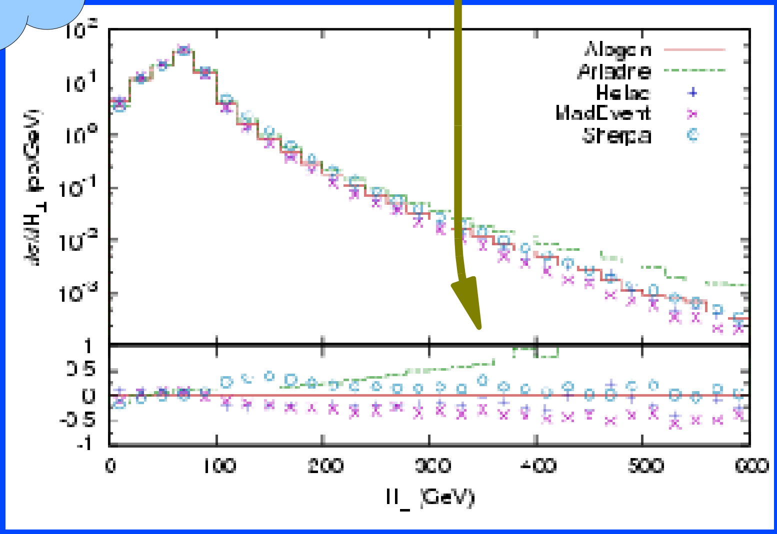
TeV → LHC

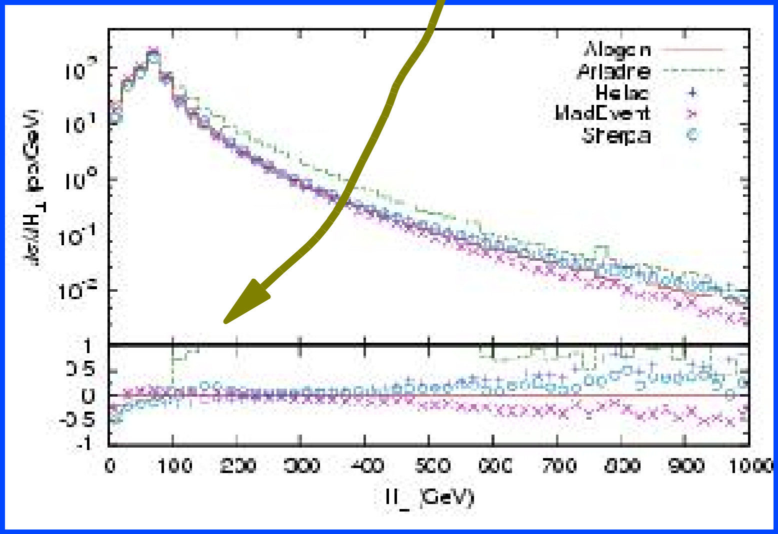
Ariadne more than DGLAP





Data more Like MLM





Sum H_T

W+charm

Direct charm + gluon splitting

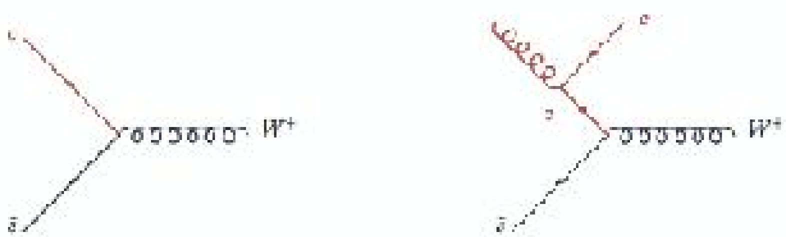
- Different game once heavy quarks are included: isolating clean event samples is not so easy.
- Serious studies only recently undertaken.

$$\frac{\sigma[W+c\text{-jet}]}{\sigma[W+\text{jets}]} = 0.074 \pm 0.019(\text{stat.})^{+0.012}_{-0.014}(\text{syst.})$$

$$\left.\frac{\sigma[W+c\text{-jet}]}{\sigma[W+\text{jets}]}\right|_{ALPGEN} = 0.044$$

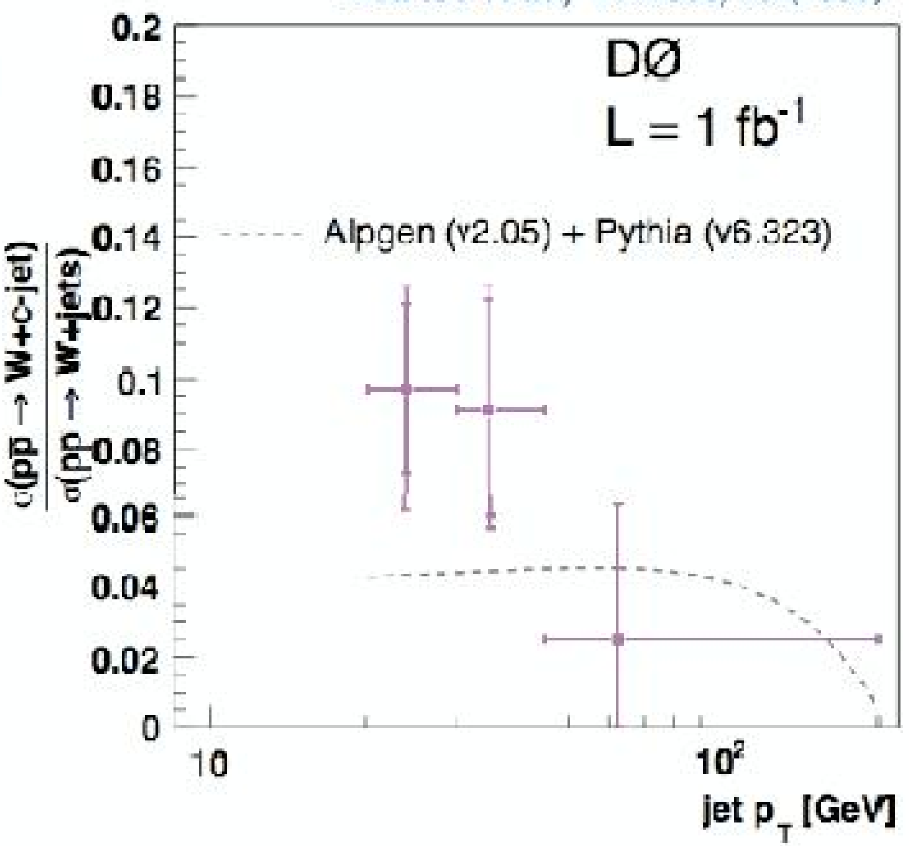
$$\left.\frac{\sigma[W+c\text{-jet}]}{\sigma[W+\text{jets}]}\right|_{MCFM} = 0.045$$

theory error ~ 10%



NB: large logs and charm PDF

Abazov et al., PLB666, 23 (2008)



- Jury still out, kinematic study essential.

W+bottom

Gluon splitting

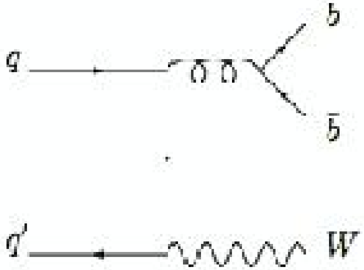
- W+1 or 2 jets, either or both of which may be b-tagged.
- Most important for single top study.
- CDF measurement:

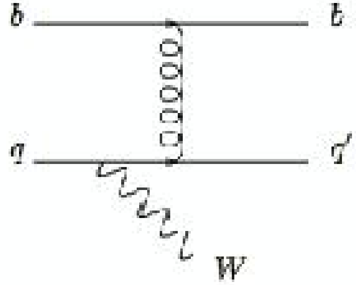
$$\sigma_{b-\mathrm{jets}}(W+b-\mathrm{jets}) \times BR(W \to \ell\nu) = 2.74 \pm 0.27(stat) \pm 0.42(syst)\mathrm{pb}$$

$$\sigma_{b\text{-jets}}(W+b\text{-jets}) \times BR(W \to \ell\nu)_{ALPGEN} = 0.78 \text{ pb}$$

CDF Note 9321

- Ongoing work to compare with ACOT formalism combining (at NLO) two sources of W+b events.



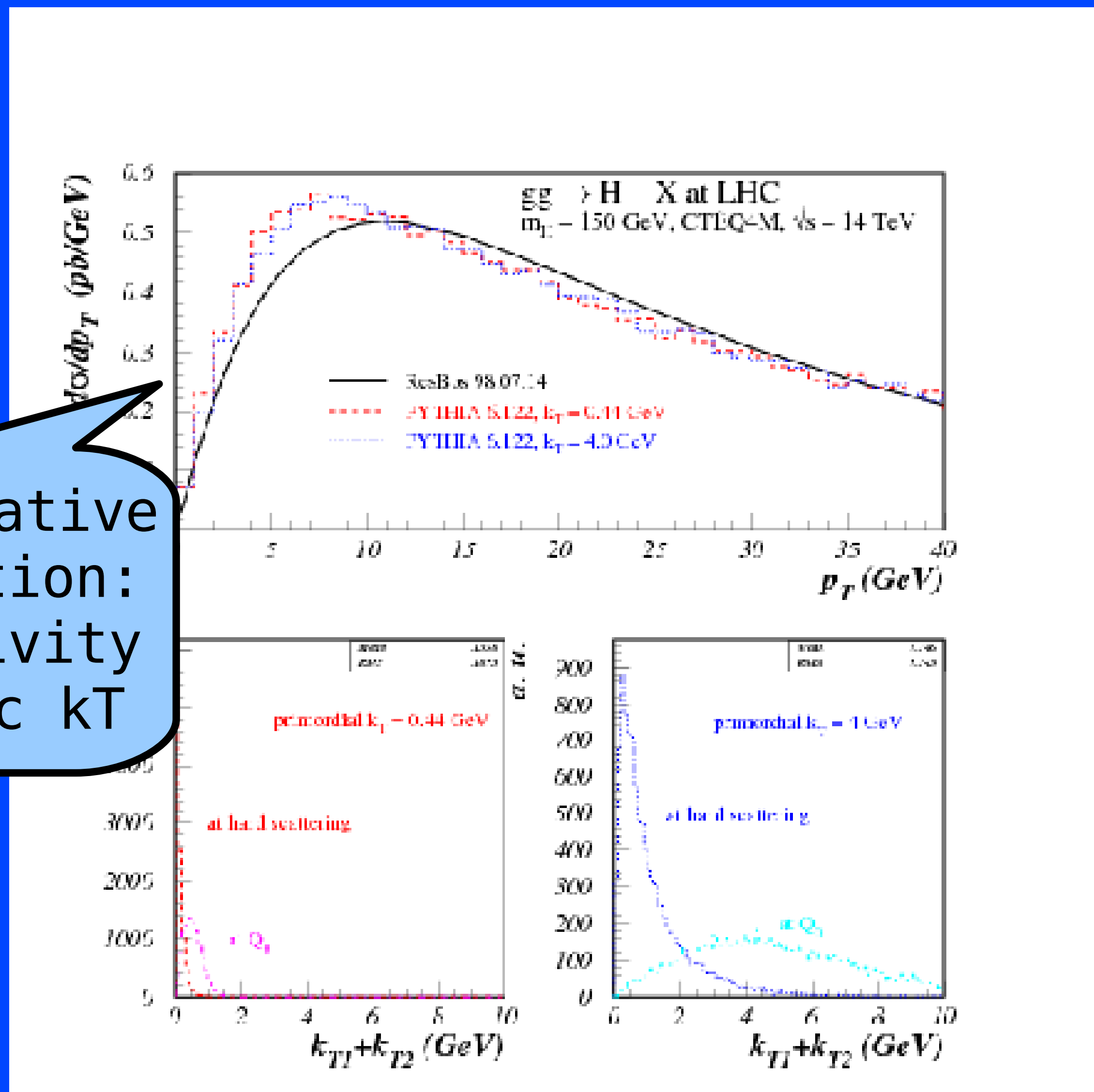


JC et al., arXiv:0809.3003 [hep-ph]

... but still hard to explain factor of 3-4

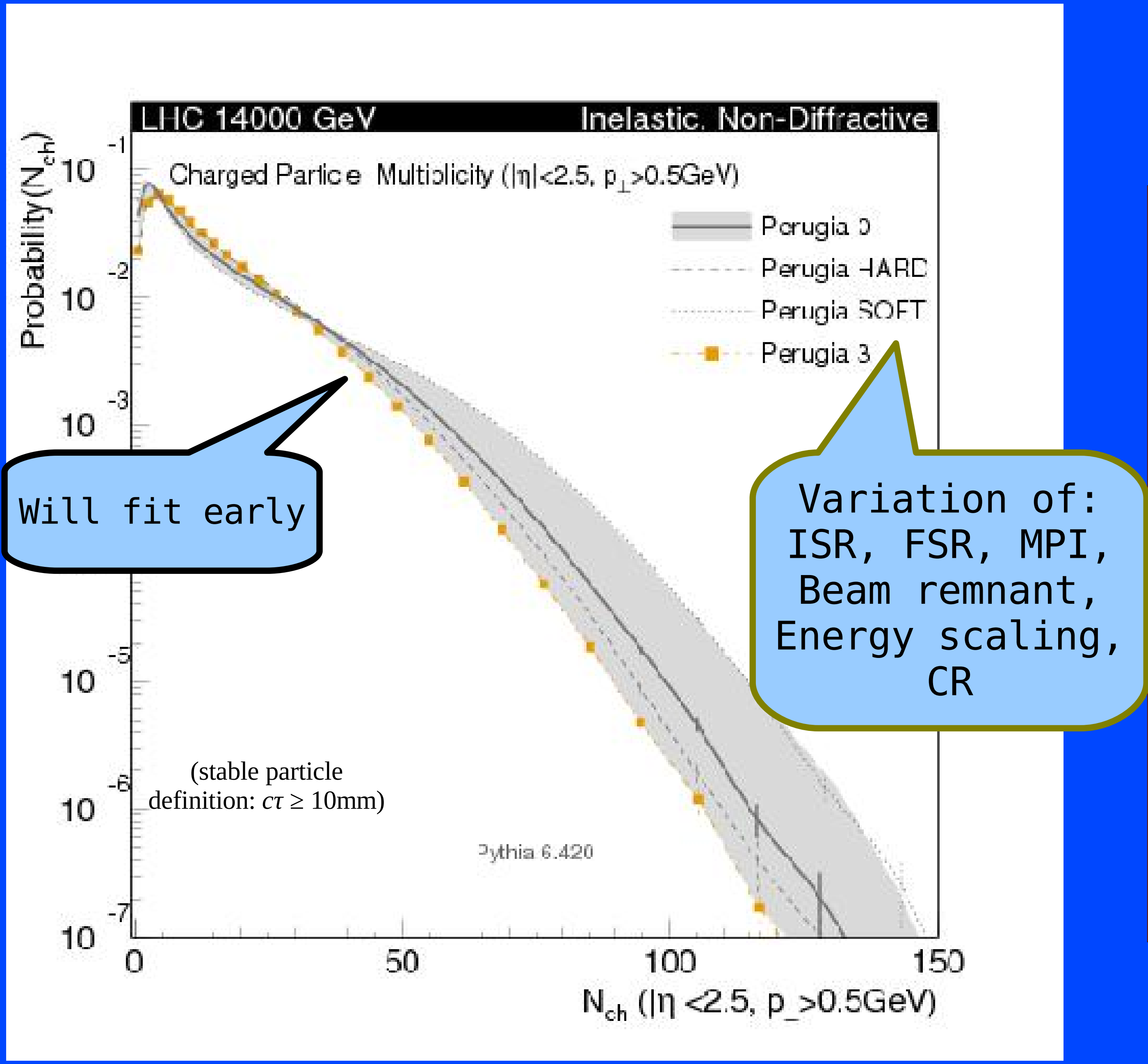
(NB: role of bottom PDF again)

Non-perturbative Effects



More perturbative gluon radiation: Less sensitivity go intrinsic kT

Perugia Models: extrapolation of UE



→ Aspen Predictions:

$|\eta| < 2.5$

$p_T > 0.5$ GeV

LHC 10 TeV (min-bias)

$\langle N_{tracks} \rangle = 12.5 \pm 1.5$

LHC 14 TeV (min-bias)

$\langle N_{tracks} \rangle = 13.5 \pm 1.5$

$1.8 < \eta < 4.9$

pT > 0.5 GeV

LHC 10 TeV (min-bias)

$\langle N_{tracks} \rangle = 6.0 \pm 1.0$

LHC 14 TeV (min-bias)

$\langle N_{tracks} \rangle = 6.5 \pm 1.0$

Desired Perturbative Variations for Shower Uncertainty

- Radiation functions
- Evolution variables
- Phase space mapping
- Internal scales
- ...

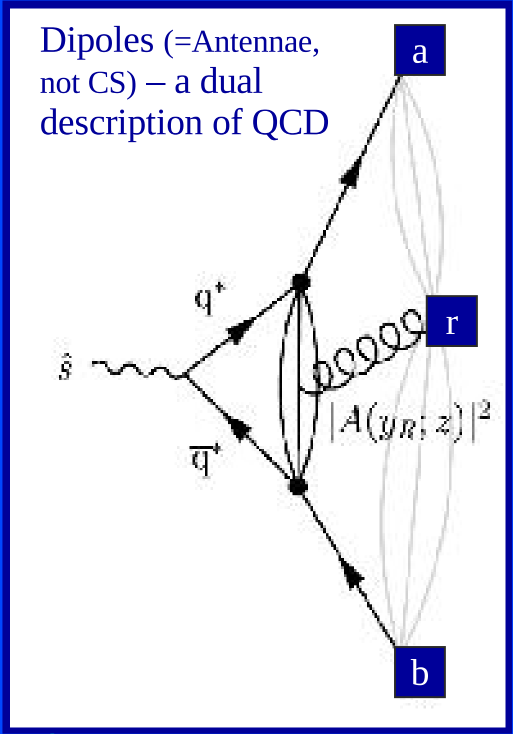
Skands/Giele/Kosower VINCIA is the closest match to this

VINCIA

VIRTUAL NUMERICAL COLLIDER WITH INTERLEAVED ANTENNAE

Gustafson, PLB175(1986)453; Lönnblad (ARIADNE), CPC71(1992)15.
Azimov, Dokshitzer, Khoze, Troyan, PLB165B(1985)147
Kosower PRD57(1998)5410; Campbell,Cullen,Glover EPJC9(1999)245

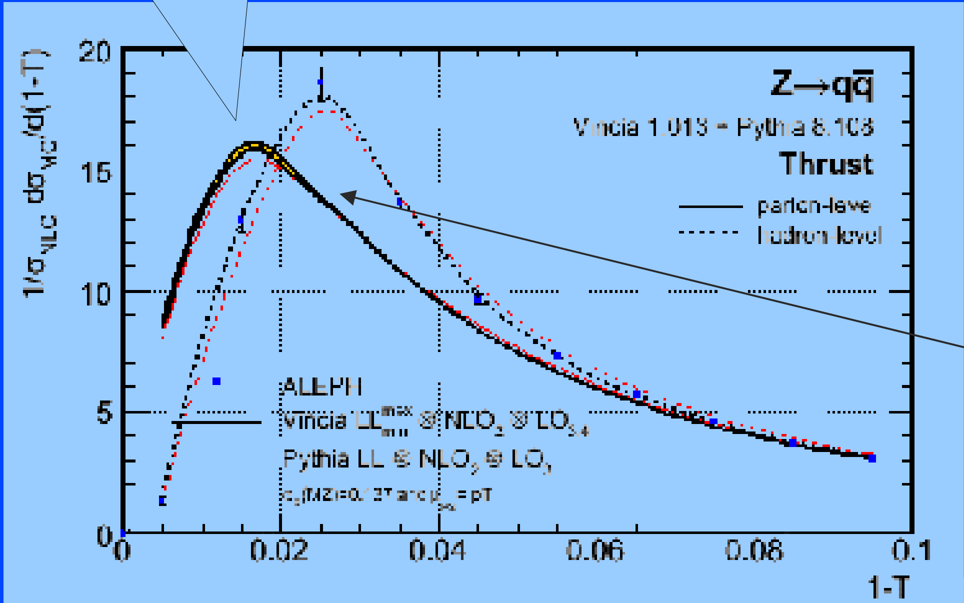
- Based on Dipole-Antennae
    - Shower off color-connected pairs of partons
  - 3 different shower evolution variables:
    - pT-ordering (= ARIADNE ~ PYTHIA8)
    - Dipole-mass-ordering (~ but not = PYTHIA6)
    - Thrust-ordering (3-parton Thrust)
  - family of antenna functions
  - Shower cutoff contour: independent of evolution variable
  - Several different choices for α_s (evolution scale, p_T, mother antenna mass, 2-loop, …)
  - Different phase space mappings:
    - Antenna-like (ARIADNE angle) or Parton-shower-like



Giele, Kosower, PS : hep-ph/0707.3652 + Les Houches 2007

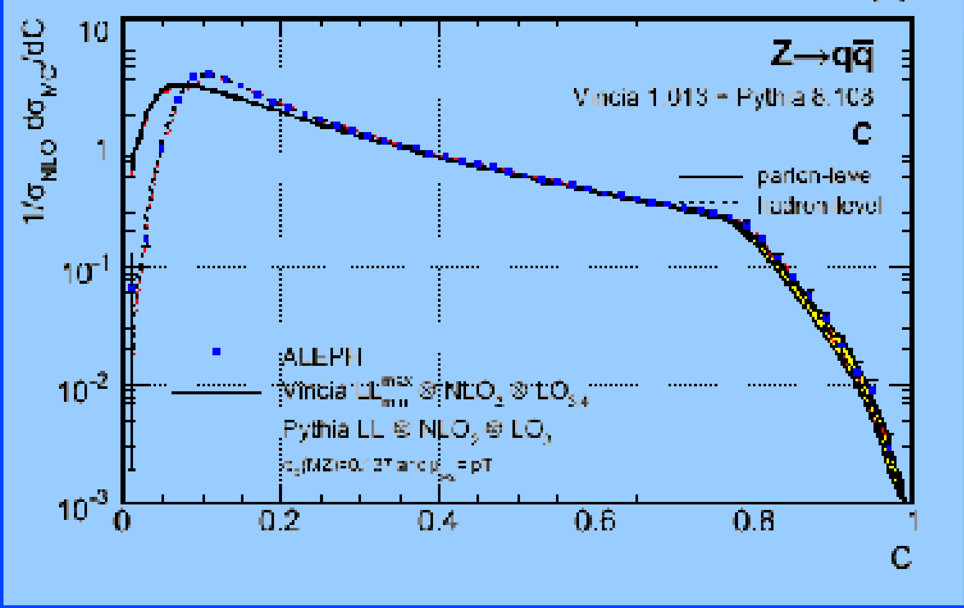
VINCIA in Action

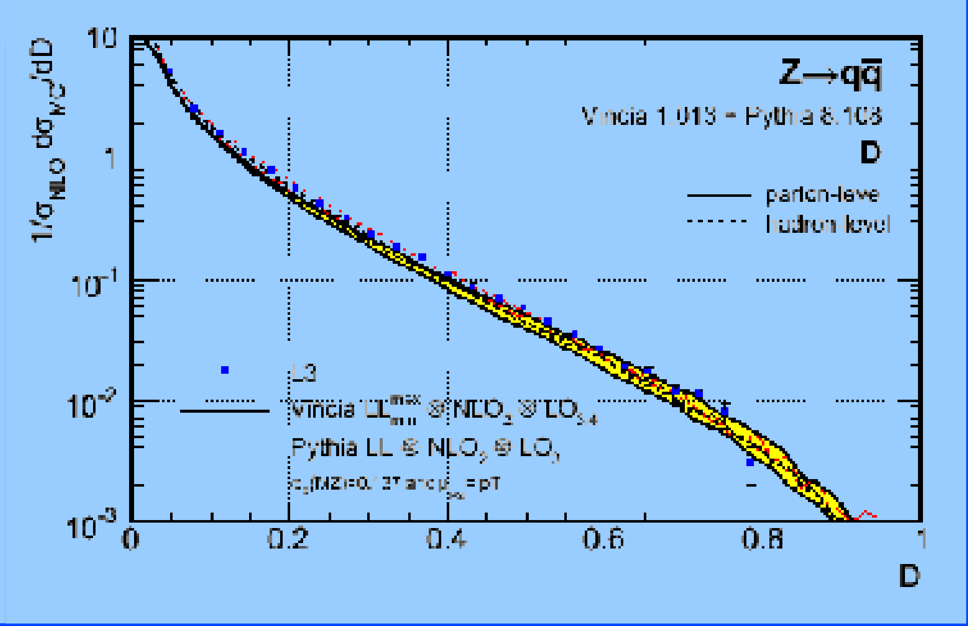
Different Finite pieces



- Can vary
  - evolution variable, kinematics maps, radiation functions, renormalization choice, matching strategy
- After 2[nd] order matching
  - ➔ Non-pert part can be precisely constrained.

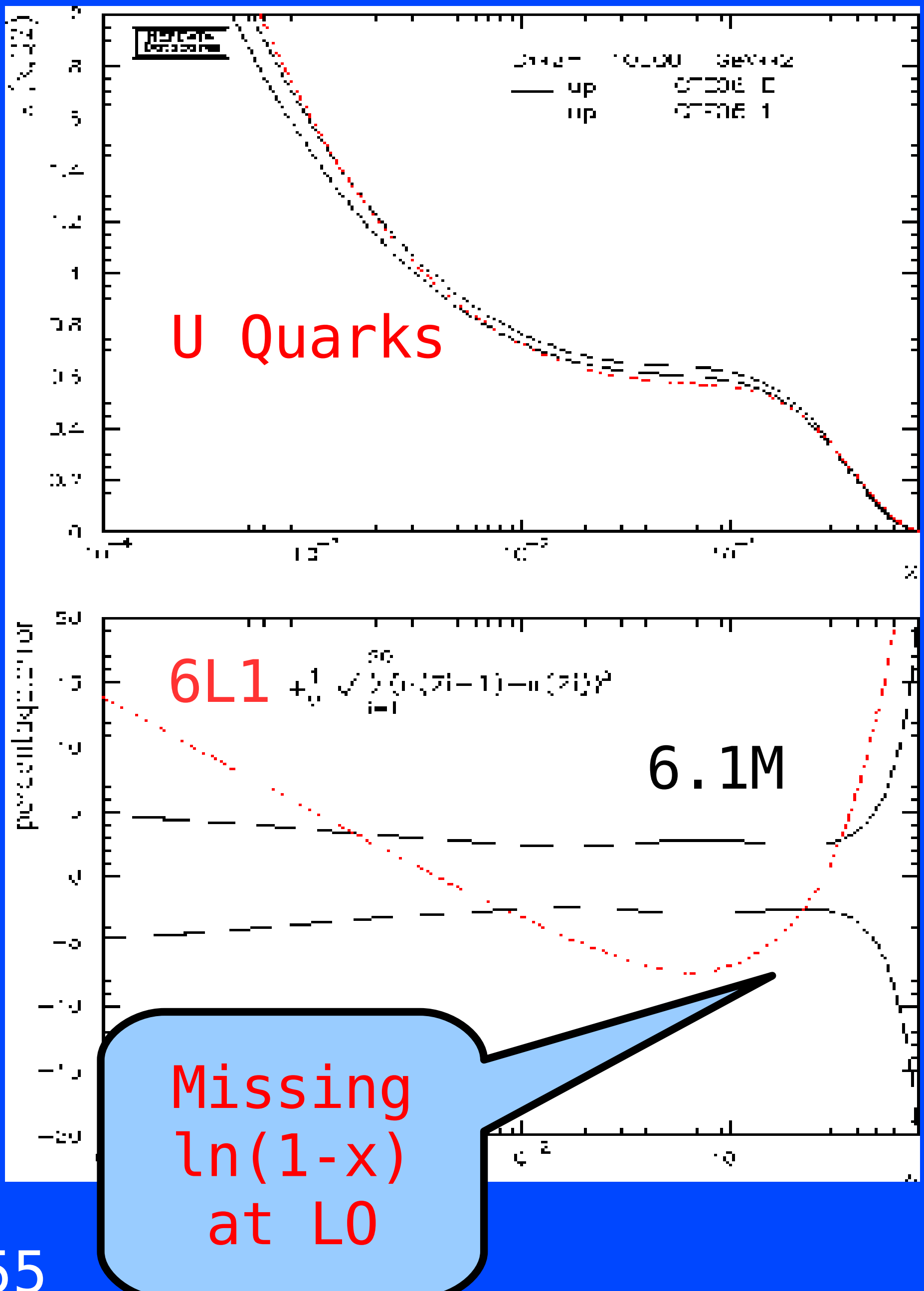
  (will need 2[nd] order logs as well for full variation)

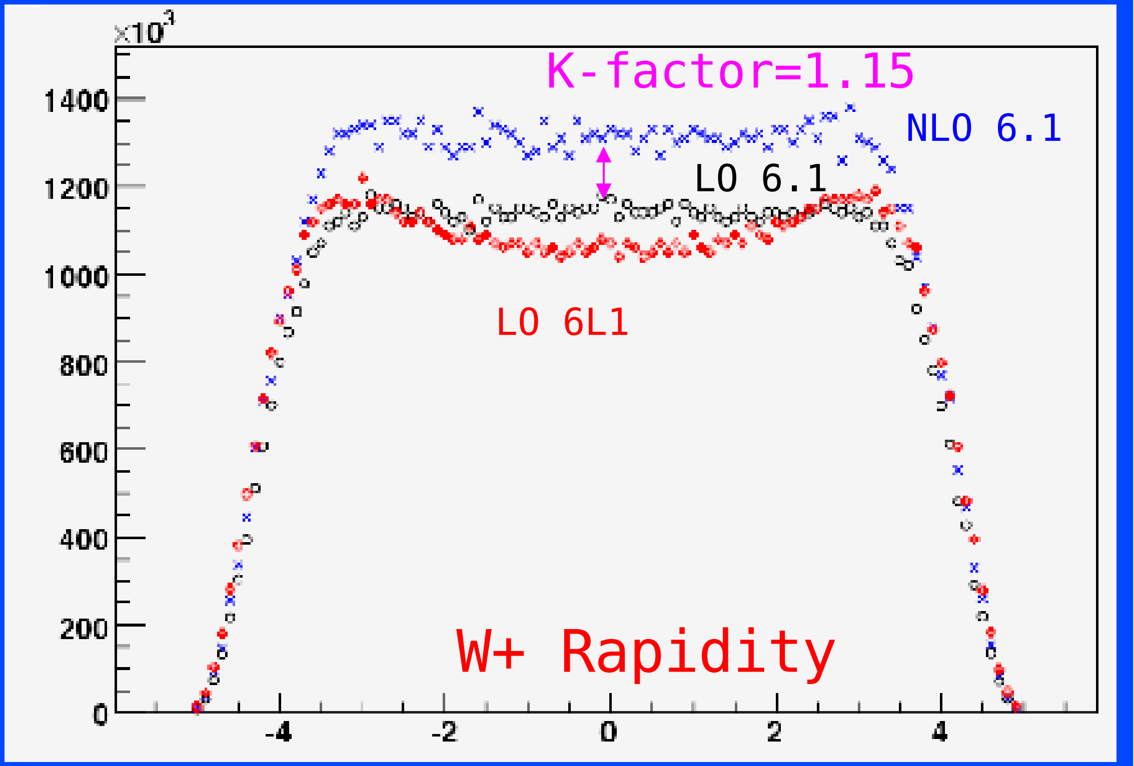




Giele, Kosower, PS : PRD78(2008)014026 + Les Houches ‘NLM’ 2007

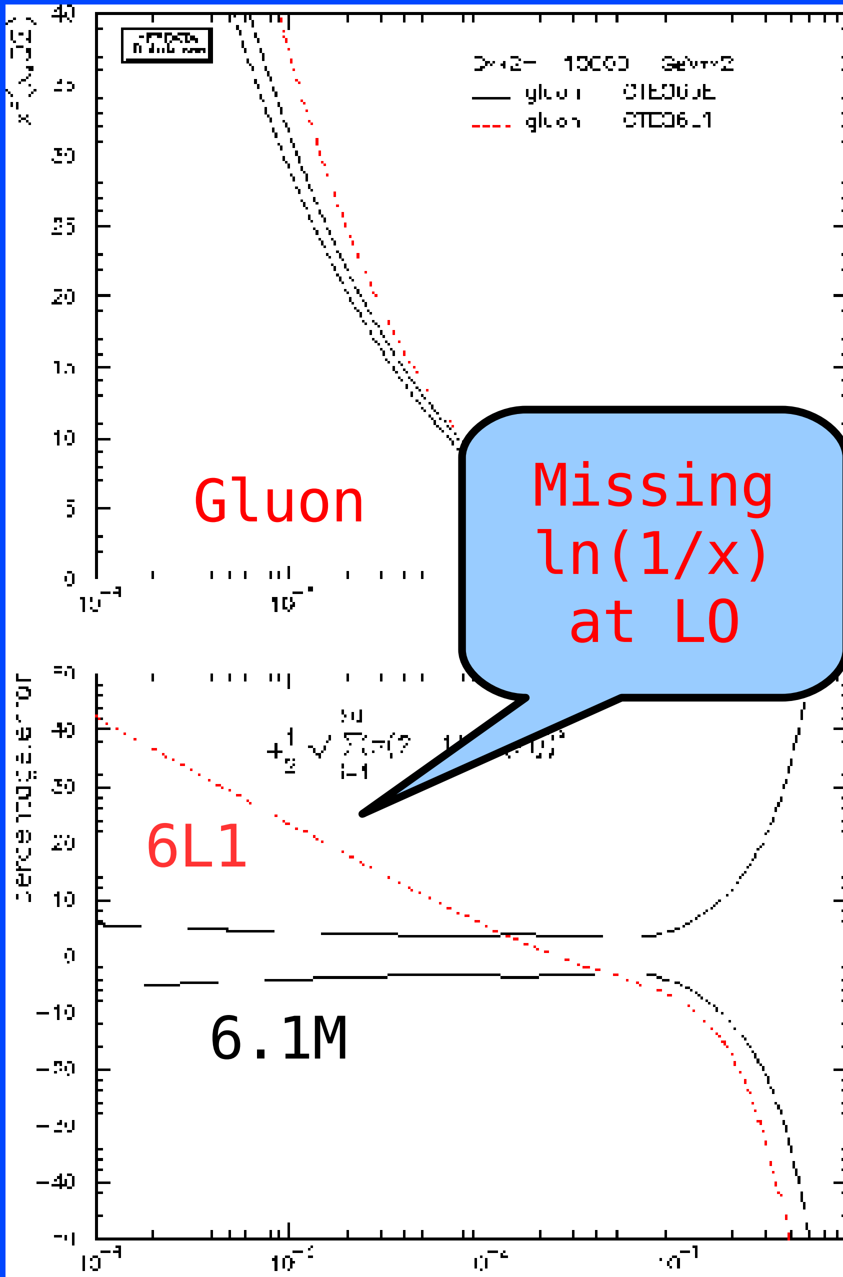
Differences between LO and NLO partons?

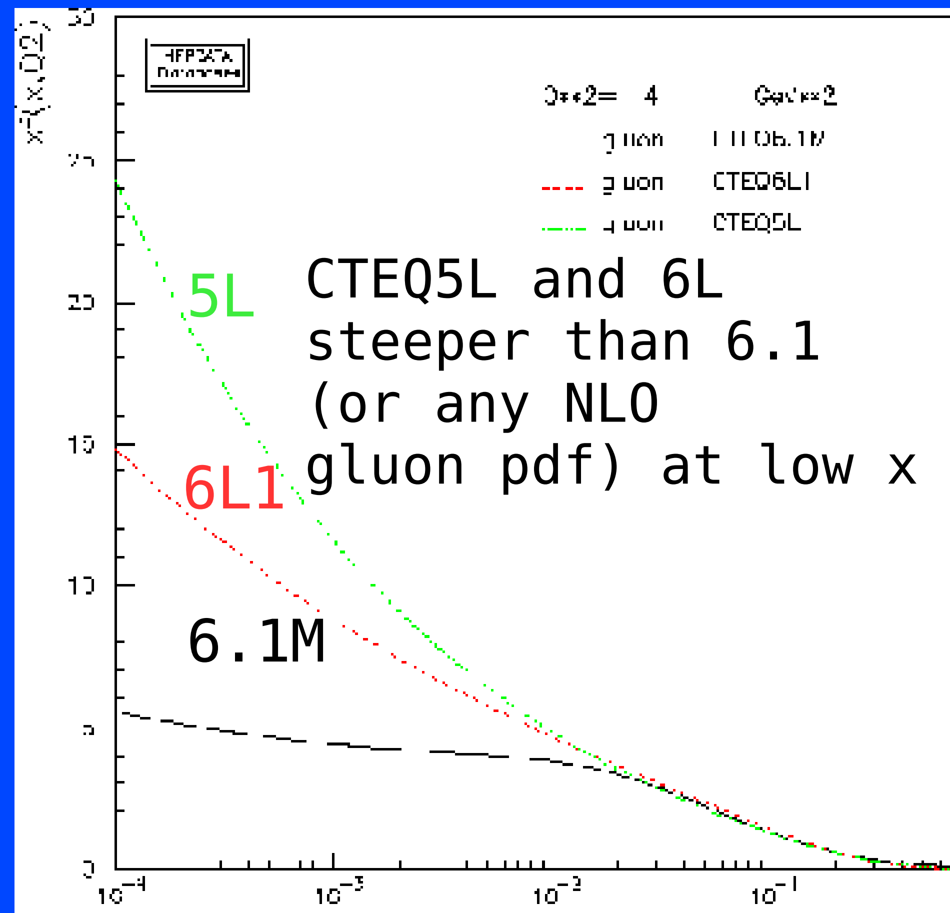




LO 6L1 == (LO ME) (LO PDF)
LO 6.1 == (LO ME) (NLO PDF)
NLO 6.1 == (NLO ME) (NLO PDF)

Where are the differences:gluons?





K-factors: how important is NLO?

Ignores shape changes

K=NLO/LO

6M/6L1

6M/6M

Process	Typical scales μ_0	Typical scales μ_1	Tevatron K-factor $\mathcal{K}(\mu_0)$	Tevatron K-factor $\mathcal{K}(\mu_1)$	Tevatron K-factor $\mathcal{K}'(\mu_0)$	LHC K-factor $\mathcal{K}(\mu_0)$	LHC K-factor $\mathcal{K}(\mu_1)$	LHC K-factor $\mathcal{K}'(\mu_0)$
W	m_W	$2m_W$	1.33	1.31	1.21	1.15	1.05	1.15
W+1jet	m_W	p_T^{jet}	1.42	1.20	1.43	1.21	1.32	1.42
W+2jets	m_W	p_T^{jet}	1.16	0.91	1.29	0.89	0.88	1.10
WW+jet	m_W	$2m_W$	1.19	1.37	1.26	1.33	1.40	1.42
$t\bar{t}$	m_t	$2m_t$	1.08	1.31	1.24	1.40	1.59	1.48
$t\bar{t}$+1jet	m_t	$2m_t$	1.13	1.43	1.37	0.97	1.29	1.10
$b\bar{b}$	m_b	$2m_b$	1.20	1.21	2.10	0.98	0.84	2.51
Higgs	m_H	p_T^{jet}	2.33	–	2.33	1.72	–	2.32
Higgs via VBF	m_H	p_T^{jet}	1.07	0.97	1.07	1.23	1.34	1.09
Higgs+1jet	m_H	p_T^{jet}	2.02	–	2.13	1.47	–	1.90
Higgs+2jets	m_H	p_T^{jet}	–	–	–	1.15	–	–

Shape dependence of a K-factor

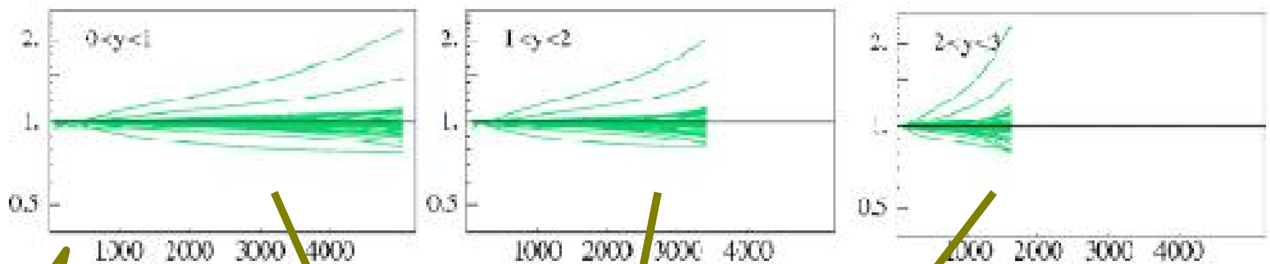


Figure 105. The ratios of the jet cross section predictions for the LHC using the CTEQ6.1 error pdfs to the prediction using the central pdf. The extremes are produced by eigenvector 15.

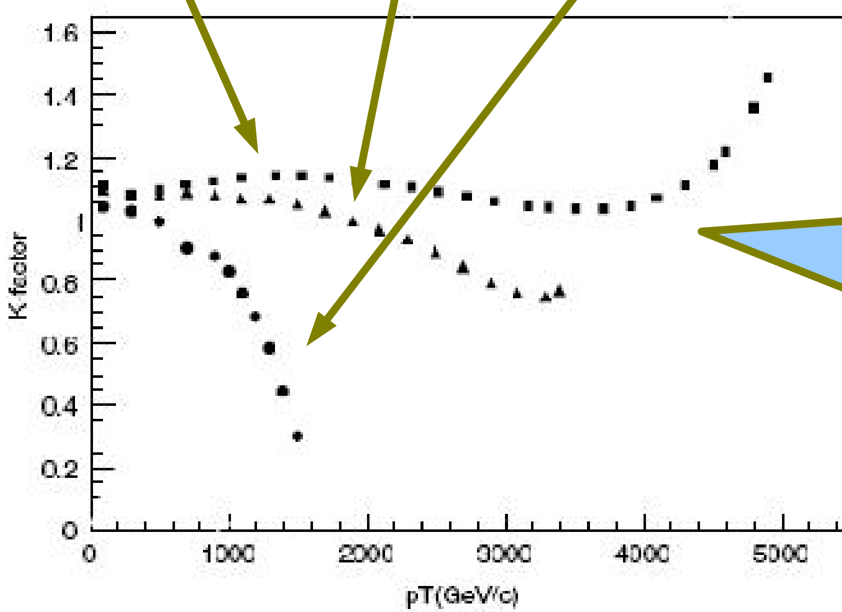
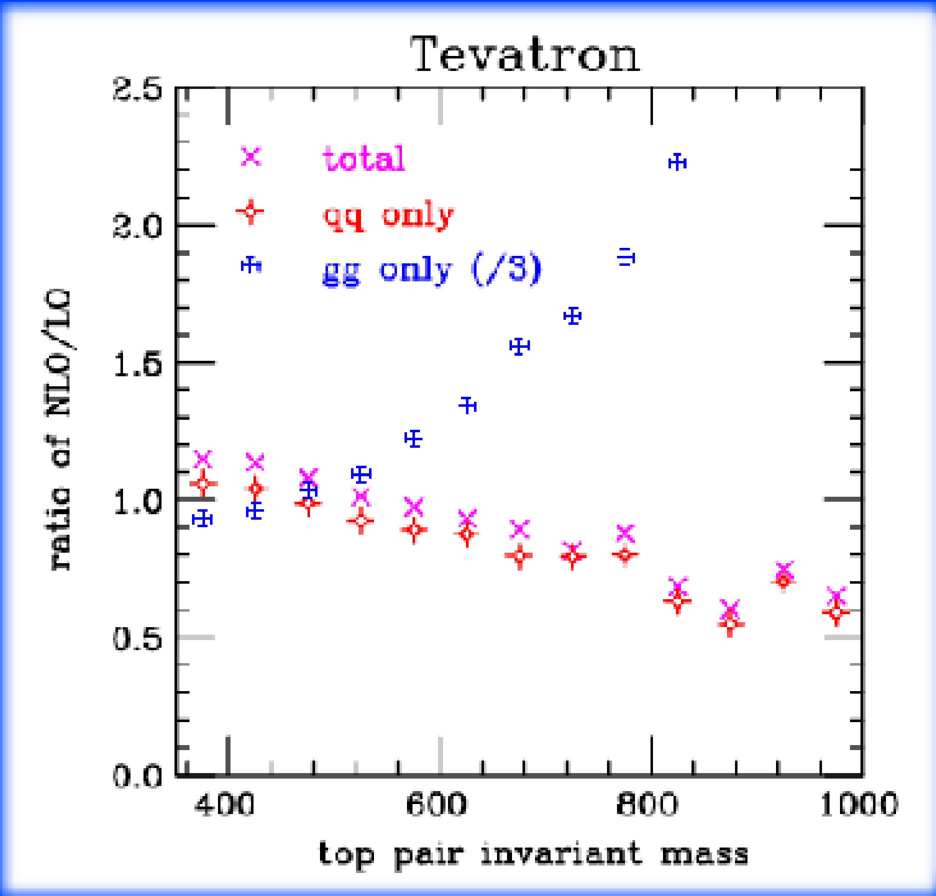


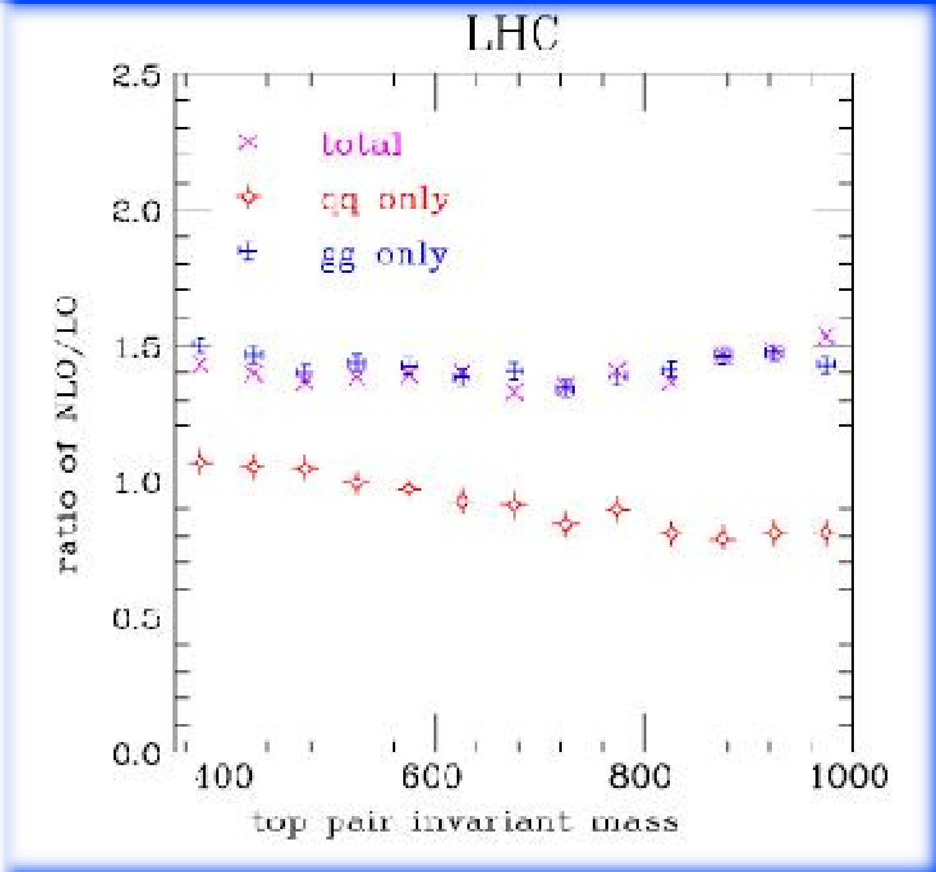
Figure 106. The ratios of the NLO to LO jet cross section predictions for the LHC using the CTEQ6.1 pdfs for the three different rapidity regions (0–1 (squares), 1–2 (triangles), 2–3 (circles)).

PDF uncertainty
Range is large

Inclusive jet:
Probes a wide
range of x, Q
Mixture of qq,gg,
qg

@TeV2 vs @LHC?


Tevatron
total
qq only
gg only (/3)
ratio of NLO/LO
top pair invariant mass
2.5
2.0
1.5
1.0
0.5
0.0
400
600
800
1000

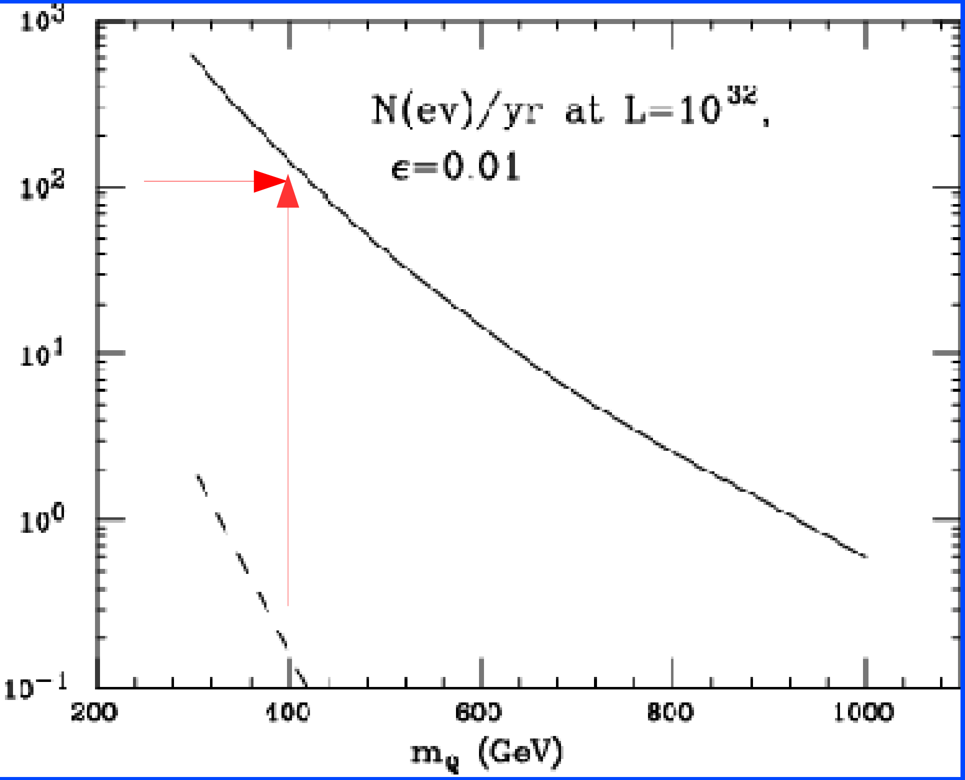

LHC
total
qq only
gg only
ratio of NLO/LO
top pair invariant mass
2.5
2.0
1.5
1.0
0.5
0.0
400
600
800
1000

What can we
expect at the LHC?

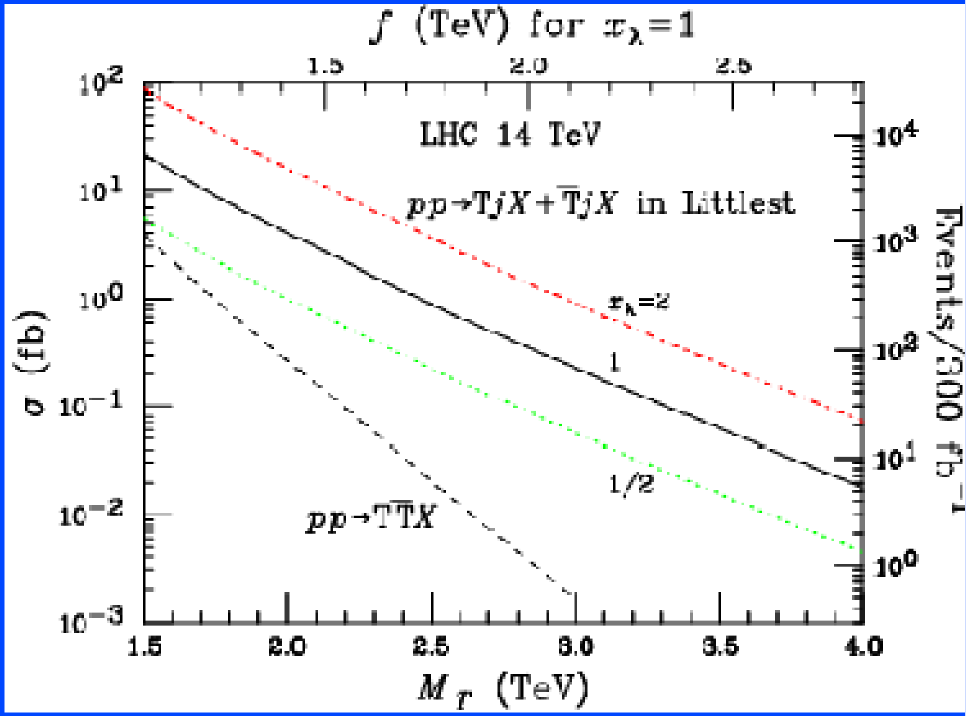
Can we understand it?

Heavy Quark Production @ LHC

Huge phase space in an interesting kinematic region

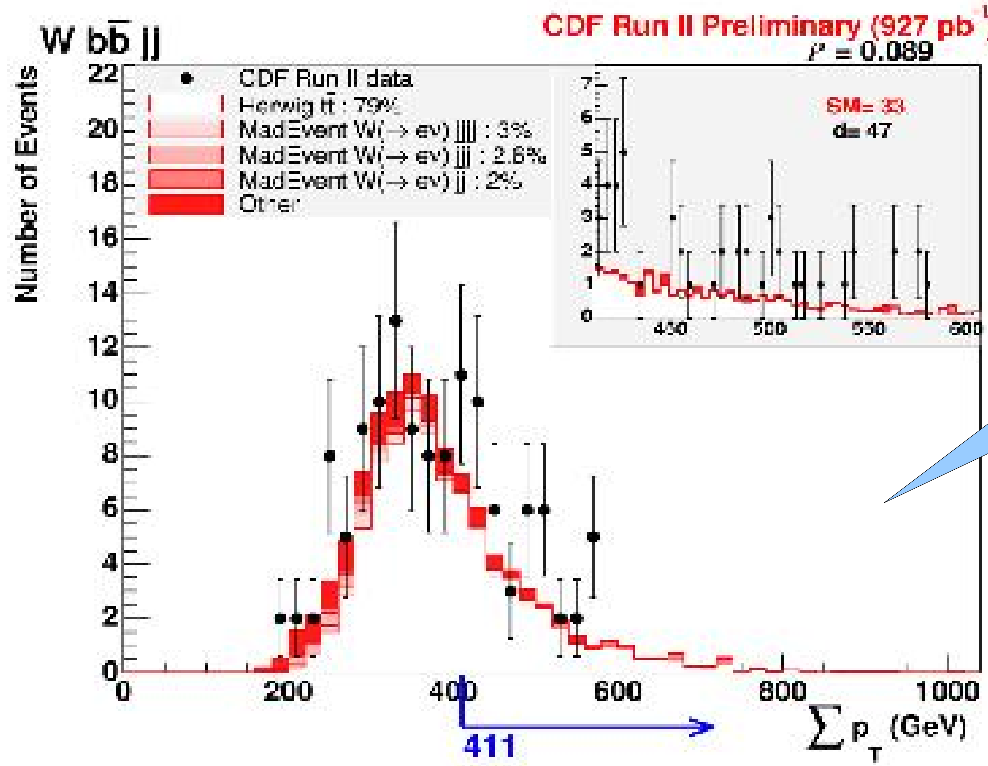


MLM

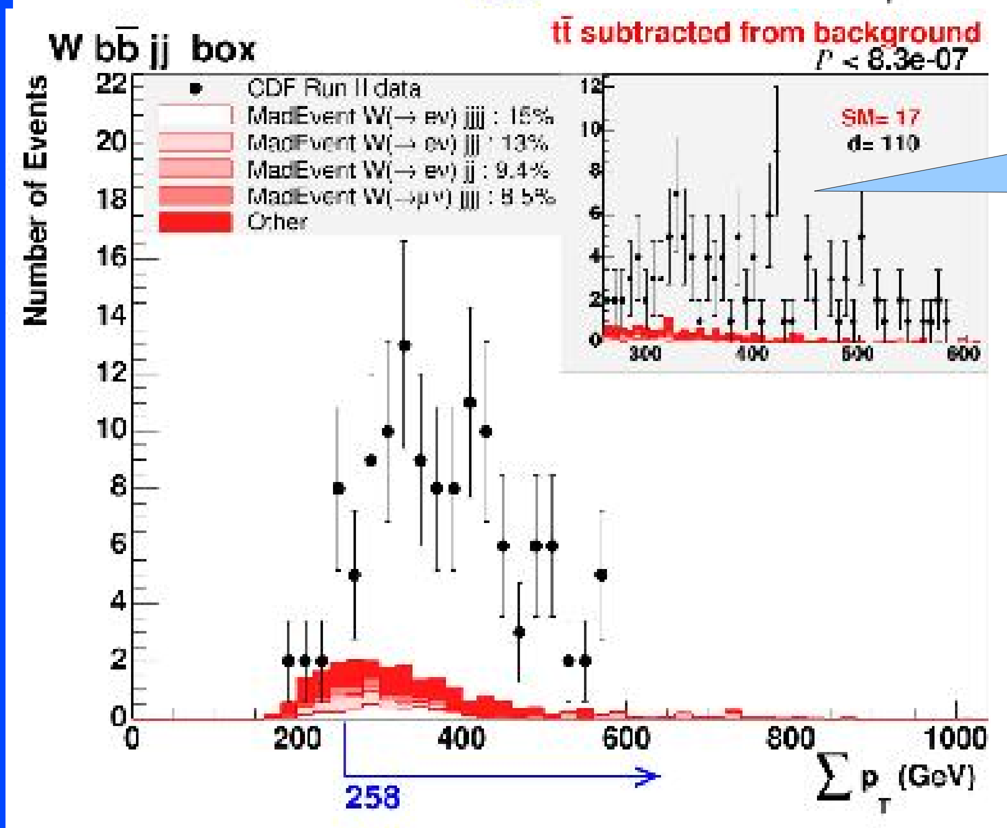


Logan, Han, Wang

Something new can appear very quickly



Would Sleuth find the top quark?



Yes in 80 pb-1
vs Run1: 67 pb-1

Possible LHC Outcomes

Something so striking
you can't miss it

$$Z' \to \mu^+ \mu^-$$

$$BH \to 100\ \mathrm{Z/W/t/h}$$

~100 GeV particles
with cascade decays

New exotica
(quirks, hidden valley,...)

Nothing

(except marginal
WW scattering)

Consequences

Easy Use sideband data as your "Monte Carlo" (probably something else to complete the picture)	**Challenging** (Control regions are all mixed up)
More Challenging Requires detailed understanding of SM (and detector) tails	**Most Challenging** When do you give up?

Conclusions

We are prepared for the challenging case. We can improve our current tools with manpower and some mindpower and understand cross sections @LHC

At the Tevatron, we have qualitative AND quantitative measures of how well we understand the SM

For early tests, data-driven Monte Carlo tools should be sufficient. But now is a good time to start worrying about higher orders and more logs